Foreword

Professor Sir Peter Gregson (Chief Executive and Vice-Chancellor, Cranfield University)

When EPSRC asked me to chair the Engineering Grand Challenges Retreat, I accepted without hesitation. It was my great pleasure to work with a group of 20 enthusiastic and talented UK Engineers from academia and industry, alongside EPSRC colleagues, at a retreat on 7-8 May 2014 at Ettington Chase, near Stratford-upon-Avon.

I was exposed to a great blend of creativity, commitment and intellectual horsepower during the meeting, and this report is a stepping stone towards identifying Engineering Grand Challenges for the next decade. Our work built on that initiated by the Royal Academy of Engineering (RAEng), in partnership with the IET and EPSRC, through the Global Grand Challenges Summit 2013. Many of the themes discussed at the Summit (e.g. sustainability, health, resilience, technology, etc.) were considered further during our retreat. EPSRC has also sought views from their UK Strategic University and Business Partners, and their responses were used as an input into the retreat.

I was particularly delighted to welcome Lord Alec Broers, who was involved in steering the US National Academy of Engineering (NAE) Grand Challenges initiative, and who emphasised the need for novel and exciting engineering solutions to the very big challenges of our time. We also heard from Prof Paul Raithby (University of Bath), who leads the EPSRC-funded Directed-Assembly Chemistry Grand Challenge Network, and who provided valuable insights about the impact of the chemistry grand challenges on UK research.

Retreat participants also heard from Prof Paul Younger (University of Glasgow) who discussed responsible innovation in research and public understanding of engineering, both highly significant topics in relation to the Grand Challenges. I would like to thank again all who contributed so enthusiastically to this debate.

The seven Grand Challenges areas that have emerged from the retreat are truly cross-cutting and interdisciplinary; they form an effective template through which strategic programmes can be formulated and milestones can be developed. The academic and user engineering research community must be ambitious and creative in order to develop long-term Grand Challenges that engage as many people as possible. EPSRC is planning some community engagement workshops for late 2014. I hope many of you will attend those events in order to further develop this initiative so it can make a real difference. Grand Challenges are a powerful tool to help shape EPSRC engineering research strategy for the foreseeable future.

Prof Sir Peter Gregson
UK engineering is flourishing. We see this in the emerging priorities of the Government’s industrial strategy (see https://www.gov.uk/government/news/industrial-strategy-early-successes-and-future-priorities), in the contribution of the engineering sector to the UK economy (28% easily identifiable contribution – see http://engineeringforgrowth.org.uk/) and in the central role that engineering research plays across the whole of EPSRC’s portfolio (Internal EPSRC analysis conservatively estimates Engineering-related investments at £931M). In January 2013 the Science Minister announced a focus on eight great technologies with engineering core to many. In the same year, London played host to a truly inspiring Global Grand Challenges Summit and the first Queen Elizabeth Prize for Engineering was awarded. Within EPSRC, we were delighted by the response to our call for Centres for Doctoral Training, both by the excitement created across the academic sector and business, and in our collective success in securing Government support.

So what was this Retreat about? Firstly, we are gathering evidence at a crucial time. A Science and Innovation Strategy is currently being developed by BIS for publication in the Autumn statement. There is an opportunity to influence the debate. Secondly, subject to considerations by the next UK Government, we anticipate a Spending Review some time in 2015. UK Engineers need to be ready – ready to inform, ready to brigade our efforts, ready to influence. Finally, the international competition is not standing still, with many nations around the world investing heavily in the scientists and engineers of tomorrow. At the same time, things are not perfect for UK Engineering. The many recent reports, whether by Sir John Perkins, RAEng and others all predict a shortage of STEM qualified professionals in future years. Diversity remains a major challenge, particularly in engineering disciplines and we continue to grapple with ambivalent perceptions within the general public towards engineering (especially parents of young people). Yet at the same time we have many opportunities to inspire – see for instance the winning videos made by young people at the Global Grand Challenges Summit (see Global Grand Challenges short film competition - http://www.raeng.org.uk/international/filmcomp.htm).

I have one question above all else: What should UK engineering research look like in the next 20-50 years? In coming to this we need to think not just about the known challenges of demographic change, future energy provision, rebalancing our economy towards next generation high-value manufacturing and others. We also need to dream and ask the ‘What if?’ questions within a global context. One major aspect of EPSRC’s mission is to support long-term, underpinning and ambitious engineering research. EPSRC is here to support research leaders and to support excellent research with impact. We are committed to build on the outputs from the retreat, validate the Grand Challenges ideas and act in partnership to take the most promising ideas forward.
Executive Summary

EPSRC is the main UK public funder of research in Engineering and Physical Sciences research and PhD training, investing approximately £800M per year. £300M of this portfolio is focused on engineering-related topics, covering areas of key capability such as ground and structural engineering, fluid dynamics, autonomous systems and synthetic biology through to challenge-led areas, critical for the future of the UK economy and society such as manufacturing technologies, carbon capture and storage or wind energy.

Part of EPSRC’s mission is to ensure that national capability in engineering is developed and sustained through a) supporting long-term and ambitious research, b) mobilising leadership in engineering-related fields and c) shaping the portfolio in relation to national need. One approach to doing this is through the development of long-term, inspiring and cross-disciplinary engineering-focused research challenges, around which the UK research community can be mobilised.

Grand Challenges are not a new concept and have been widely utilised in the UK as well as internationally, in a number of areas including computer science (2002), chemistry (2009), physics (2011) and more recently healthcare. Although Grand Challenges can be defined in a number of ways, they all have the following common features: a) they are long-term i.e. 20 to 50 years timeframe, b) they are cross-cutting i.e. they require different disciplines to work together to have any chance of solving them and c) they require coordination, collaboration and investment to make a difference.

With this concept in mind, and following the successful 2013 Global Grand Challenges London Summit, organised by the Royal Academy of Engineering, EPSRC has set out to identify a number of Engineering Grand Challenges. In order to start this process, we organised a 2-day retreat, bringing together 25 academic, industry and government experts in facilitated discussions. Prior to the event, EPSRC University and Business Strategic Partners were invited to identify, from their organisational perspective, major challenges to be met by UK engineering in the years to come. The identified challenges were used as an input to the event, and are also included in this report.

The outputs of the retreat are included in this report. Seven areas have thus far been identified as potential Engineering Grand Challenges: Risk and Resilience in a Connected World; Controlling Cell Behaviour; Engineering from Atoms to Applications; Bespoke Engineering; Big Data for Engineering Futures; Suprastructures – integrating resource infrastructures under constraint and, lastly, Engineers at the Heart of Public Decision Making.

Following the retreat, we approached 23 experts from across the engineering disciplines for their views on the themes identified; these are summarised in this document. Also given, are the results of the EPSRC Engineering Strategic Advisory Team’s discussion of the outputs of the retreat. We shall also convene a high-level group to provide initial help in refining the number of challenges and the content.

Following this, the next step in the process of refining and establishing our Engineering grand challenges lies in the running of three regional workshops in Autumn 2014. These workshops are intended to: a) engage the research and user community to identify clear
targets or milestones for each of the selected Grand Challenges areas, b) start the process of building collaborations and/or consortia as appropriate and c) Build advocacy for the Engineering Grand Challenges, particularly as EPSRC, working with its partners in academia, industry and government, is looking to build the case for Engineering and Physical Sciences ahead of the next spending review.

**Disclaimer**

The content of this report reflects individual and collective opinions expressed to EPSRC in various forums and is being shared in this report to generate debate across UK Engineering and related areas.
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1 Introduction

Following the Global Grand Challenges Summit 2013, co-organised by the Royal Academy of Engineering (RAEng) and EPSRC, the opportunity arose to explore how the Grand Challenges concept and principles (see 2.) could be applied in an engineering context. These were discussed and supported by the Engineering Strategic Advisory Team (SAT) at their January 2014 meeting. Planning for the retreat, which took place 7th and 8th May 2014, started thereafter.

EPSRC has worked in partnership with the research community over recent years to develop Grand Challenges (GCs) in a number of areas including computer science, electronics, chemistry, physics and healthcare (see Annex 8.4). Grand Challenges have also been used internationally e.g. US National Academy of Engineering (also see Annex 8.4). One common feature for all of these is that they have benefited from strong research community engagement and buy-in in order to deliver value.

Engineering GCs are inherently long-term (20-50 years timeframe) and are cross-disciplinary by nature. Above all they need to be inspiring so that they can attract the brightest UK academic minds to work collaboratively in order to tackle them. Once defined, Grand Challenges also require appropriate policy interventions in order to make progress; from coordinating the community to work together, through to supporting specific flagship research programmes to work toward solving the grand challenge.

The developed Grand Challenges will need to be communicated effectively within the broad Engineering research community - one success criterion is for the community to have understood and engaged constructively with the initiative. The GCs also need to be considered in the context of the UK government’s 8 Great Technologies (see Annex 8.4) and the Industrial Strategies (also see Annex 8.4), since they underpin much of these. Over time the Engineering Grand Challenges should also be expected to take an international dimension, particularly since they underpin the six Global Grand Challenges (sustainability, resilience, health, education, enriching life, technology and growth).

Finally, the GCs will also be used as a tool to inform long-term strategy and policy of EPSRC and other relevant organisations as appropriate (e.g. Technology Strategy Board).

2 Principles for the Engineering Grand Challenges

What could be achieved in 20-50 years if Engineers, from different research groups, disciplines and institutions, were to work in a coordinated way towards an established stimulating and common goal?

EPSRC believes that by aiding the research community to work together it is possible to accelerate progress towards major breakthroughs in science and engineering. To this end we have selected representatives from the engineering research community to suggest possible stimulating Grand Challenges which could be used as the focal point for future research endeavours. These are framed (but not directed) in the context of:

- The Global Grand Challenges (presented at the 2013 Global Grand Challenges Summit in London) i.e. sustainability, health, education, enriching life, technology & growth and resilience.
• The UK Government Nine Great Technologies.
• The UK Government Industrial Strategy.

While these challenges are to be engineering-centric they should not be exclusively for engineering to address. We would hope that research within these challenges would have the potential:

• To generate cutting-edge world-leading engineering research;
• To enable the UK's national capability to be used to best advantage;
• To have a positive impact of society and the economy;
• To stimulate collaborations between researchers in disciplines that span the breadth of engineering and beyond.

It is clear that engineering research can contribute to many globally acknowledged challenges, such as, for example, providing clean water for everyone, preventing natural disasters, through improving healthcare technologies and developing the next generation of future energy technologies. The Engineering Grand Challenges are there to galvanise the research community to work together on crucially important problems.

We acknowledge that it is not always possible to identify the most important developments in advance, and that major breakthroughs will continue to come from outside any agreed set of challenges. However, hopefully the challenges discussed here will resonate with a great number of engineers, encouraging them to work together and with researchers from other disciplines to achieve significant breakthroughs and outputs.

3 Aims of the retreat

The main aim of the retreat was to develop a small number of long-term (20-50 years) cross-disciplinary grand challenges, around which the UK Research Community might be galvanised. The retreat was attended by around 20 recognised researchers from academia and industry at different stages of their careers, drawing on expertise from across the engineering disciplines (see attendees list in Annex 8.2).

The idea behind the Retreat was to get the participants to think freely and explore the unexpected. The principle of the retreat was that there could be no wrong answers, and the aim was not primarily consensus building at this stage. Retreats are one of a range of activities that EPSRC has developed over the years in order stimulate creativity and facilitate horizon-scanning, and it was felt that this might be an appropriate mechanism to start to discuss Engineering Grand Challenges.

The desired outcome for the retreat was to develop a list of Engineering Grand Challenges which would be developed further and refined during the course of 2014, drawing on the help of the attendees, and, crucially, through broader engagement with the engineering (and related disciplines) research and user community.
4 Retreat Outputs – Engineering Grand Challenges Themes

The seven themes identified at the retreat are closely interconnected and delegates were asked to identify where overlaps might exist between the different themes. The diagram below is an attempt to visualise those connections.

**Figure 1 – Basic visual representation of the connections between the seven Engineering Grand Challenges**

4.1 Risk and Resilience in a Connected World

**Description**

This Grand Challenge relates to Complex Systems i.e. systems where events at one scale can influence outcomes at another, and/or where multiple interconnections at one scale exist, with emergent behaviour then occurring. Examples are complex products consisting of many components such as a jet engine which depends for its operation on a large number of interrelated, physical interactions, and/or a complex network, such as an electricity distribution grid deploying smart metering and signalling across diverse power supply generators and demands. The key focus of this challenge is on the move from simple to complex engineering solutions.

There are a number of sub-challenges which will need to be tackled under this Grand Challenge including, but not exclusively:

- Build modelling capability and decision making tools for complex systems that are highly networked and dynamic;
• Predict behaviour in the presence of uncertainty, complex combinations of risk factors, and emerging behaviour;

• Design for performance and efficiency:
  o at low risk, low cost, and with high economic output
  o minimising environmental and other negative impacts;
  o negative ensuring safety and reliability..

• Control
  o Focus on systems integration and methodology;
  o Ultimately embedding new approaches in the system leading to better problem solving

• Move away from specific component design codes to through-life product performance engineering (at an appropriate level of complexity).

• Make complexity accessible to all stakeholders:
  o To ensure they are not overwhelmed by complexity;
  o To enable us to turn complexity to our advantage;
  o To allow visualisation of the appropriate degree of complexity;
  o To enable recognition of the ‘Excitement factor’ – allowing us to solve problems that cannot otherwise be solved.

Who needs to be involved?

Systems engineers need to become ‘complex systems’ and ‘systems of systems’ engineers – this includes domain experts for specific applications (e.g. computer/electrical networkers/engineers); or civil engineers (e.g. road/water networks), as two of many simple examples. There is a real need for new and additional capability to tackle this grand challenge effectively.

Pluses and potentials

This cross-cutting engineering Grand Challenge has very wide and generic applicability across scales and sectors – it has the potential to push the boundaries of current knowledge. It is intrinsically linked to at least two of the other Grand Challenges identified at the Retreat (e.g. suprastructures and engineering across scales). Through it a better understanding of how to analyse or control large networked design systems would be enabled. It has the potential to create a systems framework applicable to different areas of decision-making (e.g. political, economic). Such an engineering grand challenge could generate solutions or trade-offs to many currently known but difficult to solve problems.

Concerns and opportunities

How one might communicate this Grand Challenge to the public and convey a sense of excitement about solving it is a challenge in itself. One way to do this may be provide some clear examples and/or application areas (e.g. water-food-energy nexus, financial markets, the brain, computer networks, industrial systems, supply chains, renewable power generation, engines, industrial emissions impact, etc.).
“A complex system is greater than the sum of its parts; it behaves in a way which is fundamentally different to that of its individual components functioning independently”. Such a statement might help explain the Grand Challenge in reasonably simple terminology for non-experts. Replacing the word ‘complex’ by other words such as ‘networked’ or ‘integrated’, when referring to systems might help public understanding of the topic and allow this to be viewed more positively.

One might also ask what is stopping researchers from solving the Grand Challenge using current ‘known’ tools – there is clear link to ‘Big Data’ and mathematical complexity which should be explained clearly and simply to the public. However, there is a need to move one step further from what is in use at present. There is also a need to explain that the Grand Challenge covers both connectivity of components and systems as well as relationship of systems across scales (e.g. from the macro to the nano-scale).

**How is the UK currently positioned to tackle this grand challenge?**

There is already a strong research base working in systems engineering, for example and there is generally a strong systems focus across the research community (e.g. energy, transport & water). The UK mathematical sciences and climate science research communities are strong and could readily engage with this Grand Challenge but other areas would emerge. There is a clear link to High-Performance Computing (HPC) and pre-existing consortia making use of HPC capability. There is a real opportunity to engage with policy-makers across the economic and political spectrum (e.g. Chief Scientific Advisers). Sectors such as finance (modelling, markets) and gaming are likely to have a strong interest in this area as it underpins so much of their everyday challenges.

**What might be needed to help solve the Grand Challenge?**

A number of interventions may be needed:

- A network or forum would be an effective stimulus to bring groups together – such network would need to engage all engineering disciplines and those relevant beyond (e.g. mathematical sciences, HPC, climate science, computer science, etc.).

- Stakeholder engagement in its broadest sense will be crucial - communicating complexity more simply to them is key.

- Investment in supercomputing outside 5 year horizon will be needed.

- Multi-dimensional analysis capability will be crucial.

- Outreach to connect systems to “life”.

**Contacts from the retreat**

Claire Adjiman, Mark Savill, Shane McHugh, Ken Grattan and Dragan Savic
4.2 Controlling cellular behaviour

Description

This grand challenge is centred around the development of new and novel engineering approaches to the design, creation and control of biological systems for a variety of applications. The key to this challenge is that new approaches are needed to design devices, molecules, and surfaces which can guide cells to perform a specific target function, whilst allowing for other biological functions and mitigating against systemic effects. The challenge encompasses bio-inspired and biological systems engineering, and will bring together researchers from diverse backgrounds to consider both control engineering and systems design approaches to a range of biological problems as well as biological solutions to engineering problems. Research under the umbrella of this challenge has the potential to impact on theranostic (therapeutic and diagnostic) approaches and technologies, advanced materials, bio-production, agro-science, bio-energy production and regenerative medicine amongst others.

Sub-challenges within this challenge may focus on:

- Design of biological molecules, biomedical devices, and biological systems to behave according to specifications.
- Systems and control approaches to cellular and molecular scale engineering, for applications including the pharmaceutical, biomedical and biotechnological industries.
- The design of chemically or structurally new bio-materials that provide cell guidance; for applications including regenerative medicine.
- Development of new engineering models and design methods for biological systems and biomedical devices, by combining biological understanding and need with engineering solutions.
- Developing an engineering design cycle for control of cells.
- New multi-scale characterisation and measurement approaches for biosystems.
- Sensors, new diagnostic techniques, and related data handling and analysis methodologies to support design of devices and materials for cellular control.

Who needs to be involved?

Systems and control engineers will need to work together with functional biomaterials engineers, bioengineers, and chemists, including the ‘beyond the molecular’ network. Furthermore, there is a clear need to involve those with advanced manufacturing and bio-process expertise, as well as expertise in instrumentation, diagnostics and sensor devices. As much of the work in this area would have an eventual clinical and/or bioindustrial application, integration of clinical and industrial colleagues and biologists into the research pathway will be crucial to understanding not only technology push, but also clinical, biological, and industrial pull.
Pluses and potentials

This challenge brings together several different aspects of engineering, along with researchers both across and beyond the EPSRC remit, and will hopefully stimulate new and novel engineering approaches to biological problems, as well as having impacts within other fields.

Outputs from this challenge could have a very wide range of application areas and inputs, including in health, manufacturing, environmental remediation, and (bio)energy generation. There is a real potential for need-driven research in this area, where needs may be identified by a range of stakeholders; engaging with such parties will be key to determining novel sub-challenges. In order for successful outcomes to be achieved from this challenge, researchers from both across and beyond the EPS space will have to come together to work on this challenge, outside of their usual spheres.

Concerns and opportunities

A key concern for a challenge of this nature will be to ensure that engineers are not creating solutions to non-problems, with engineers needing to be linked up to biologists, medics and other problem owners in order for there to be user pull as well as technological push for their innovations. This challenge should be seen as an opportunity to bring together such problem owners with engineers, in order to find engineering solutions to key questions, including the development of new measurement and instrumentation capabilities. This challenge encompasses many current challenges from within fields including synthetic biology, biomaterials engineering, process engineering, systems and control engineering, and manufacturing. Rallying researchers to consider broad challenges outside of their usual field may be difficult without clearly identified initial questions, and the success of this challenge may depend on the presence of a core network or other leadership.

How is the UK currently positioned to tackle this grand challenge?

The UK has key strengths, talented researchers, and a very strong core knowledge base in underpinning areas; across biology and synthetic biology, systems and control engineering, biomaterials, in silico modelling, and a range of other fields. Furthermore, many of these researchers are accomplished interdisciplinary workers, with demonstrated leadership in their respective areas, and are commonly tackling challenges outside of their core expertise.

What might be needed to help solve the Grand Challenge?

A number of interventions may be needed, including:

• A network to shape and consider the challenge, which may need to be formed through an event or events.

• A mechanism to ensure that end users, industry, and other stakeholders are involved in the posing of research questions, the research process and translation.

• Investment in computing power and instrumentation for real-time analysis & feedback control engineering
• Research and development in underpinning theranostics, advanced materials, manufacturing, data handling for bio-control purposes and real-time non-invasive biosensors.

• Question: do we have centres/laboratories equipped with the right kit and people today to solve these problems or is new investment needed?

• Public engagement and educational activities around the risks and research questions as part of a responsible innovation and acceptability strategy.

Contacts from Retreat
Julian Jones, Guy-Bart Stan, Sarah Spurgeon and Alison Noble

4.3 Engineering From Atoms to Applications

Description
This Grand Challenge deals with how to design across the scales for both products and systems, albeit each could be treated as a grand challenge in its own right. ‘From molecules to markets’ could also be used to describe the Grand Challenge.

There are a number of topics to consider under this Grand Challenge including, but not exclusively:

• The importance of microstructures – bridging the meso-scale gap from atoms to bulk and from molecules to continuum;

• Static and dynamic – performance considerations including predictions of costs;

• Linking and communicating between models of different physics and different time and space scales e.g. deciding how much information needs to be carried across the interface;

• The need to achieve sufficient accuracy at each level and in models to allow data to be transferred up and down scales (e.g. from finer to coarser scales);

• The development of effective, usable, practical and robust models for use in industry as well as research;

• Product and process interaction – recognising that the manufacturing process changes depending on the material and thus the properties;

• Through-life development e.g. re-use and recycling;

• Measurement: the right measurement appropriate to the relevant scale.

Who needs to be involved?
All engineering disciplines, manufacturers and users of the research (e.g. composites, metals, formulation products, ceramics, polymers, coatings, separation membranes, aerospace, defence, marine and automotive), physicists, mathematicians, chemists, High-
Performance Computing (HPC) experts and materials scientists need to work together to tackle this grand challenge.

Examples of applications or products could be:

- Coatings for ship hulls designed for low friction and to prevent bio-fouling;
- Highly-efficient desalination or wastewater-remediation membranes (this was also one of the short-listed challenges for the £10M Longitude Prize 2014);
- Molecular sorting for highly efficient chemical reactors;
- Active flow control devices for reducing turbulent drag on aircraft wings;
- Robust, long-lasting surface texturing of cars and other vehicles for to prevent dirt accumulation;
- Control of other processes at the molecular level.

**Pluses and potentials**

The Grand Challenge is both practical and important. It provides a clear integrated way of thinking and will lead to smart products, bespoke devices and has clear industrial relevance. It offers great potential for accelerating routes from ideas to markets and could provide new ideas for zero-prototyping, optimisation and engineering scale-up. There is also a clear link to the development of new scientific instrumentation to allow the right measurements to be made reliably and cheaply within this challenge as well as to other challenges associated with multi-scale manufacturing and chemistry.

**Concerns and opportunities**

There is a current lack of skilled people in the UK. Availability of HPC is also a risk for the future. It is important to get buy-in from across the disciplines since language and interpretation of the Grand Challenge could lead to confusion. Expertise in physics across other disciplinary boundaries is also required. Coordinating links to related activities such as the EPSRC Chemistry Grand Challenges, relevant research consortia (e.g. HPC for engineering consortium CCP12), and Centres for Doctoral Training (CDTs), relevant Masters Courses and projects is an opportunity. Many elements of this will be interdisciplinary in nature.

**How is the UK currently positioned to tackle this grand challenge?**

There is already a clear vision as to what the Grand Challenge is and there is no need to start from scratch as UK has good reputation in some of the fundamental modelling areas. There is already reasonable access to HPC facilities to get work going. Distribution of expertise in academia and industry is good across the UK and there is clear appreciation of needs both in universities and businesses. The High-Value Manufacturing (HVM) Catapult Centre offers good focus in terms of industrial input into the Grand Challenge. There are also a number of relevant Centres for Doctoral Training (CDTs) associated with the Grand Challenge.
What might be needed to help solve the Grand Challenge?

The skills gap needs to be addressed in the UK e.g. strong mathematical materials scientists are needed. A network to help build integration across people and disciplines, as well as to get broad buy-in and help define fine details of the key problems, is needed. Securing additional HPC funds (i.e. ARCHER) would really help tackle this grand challenge. There is also a need to generate training in generic multiscale modelling platforms. Measurement in real time at small scale (e.g. surface changes) needs to be improved.

Contacts from Retreat

Jason Reese, Andrew Bayly, Kevin Potter, Mark Savill, Claire Adjiman and Julie Yeomans

4.4 Bespoke Engineering

Description

The challenge looks at how new technologies are enabling people to explore a new set of possibilities that will ultimately make engineering bespoke and personalised. By addressing this challenge we could make people realise how engineering has evolved and will continue to do so at a rapid pace and thus is always adapting to people’s social needs and communities more widely.

Sub challenges may focus on:

• Develop ways to enable individuals or groups (e.g. businesses, local communities, charities, educational institutions) to have unique and personal products to fit their needs.

• Develop supply chains for both individual and corporate worlds.

• Minimise waste in production– developing new uses for materials and only use what is needed.

• Societal aspects: Identify and quantify physical and cultural need of individuals.

• Develop suitable regulatory frameworks.

• Disruptive: new design and manufacturing production processes.

This challenge needs new technologies, methodologies and integration, whilst considering carefully the societal dimension that comes with it

Who needs to be involved?

There are a number of disciplines that should be involved to make this challenge possible, not least the manufacturing sector but also:

• Metrology Information Technology issues, miniaturisation, material sciences;

• Chemical and process engineers, control engineers, engineers doing multi-scale simulation and design;
• Scientists as appropriate to the targeted application (e.g. pharmaceutical chemists for personalised drugs).

Pluses and Potentials

The challenge needs to be kept broad not just thinking of everyday products but be ambitious and look at other sectors such as chemicals for consumer products and manufacturing of medicines. If addressed successfully tools could be developed to automate design, manufacture and assemble products shortening timescales to market and making engineering appealing to society more widely. It has also significant environmental potential for using materials more efficiently and responsibly.

Concerns and Opportunities

Societal aspects of this research need to be considered with care to prevent this technology being seen as invasive – people should be empowered and the user should be positioned at the heart of the technology. Controlling processes across the scales for those new technologies, devices or materials is critical to ensure they can be used properly once developed. Although research in this area is, in some aspects, already taking place, one challenge is in branching out towards other fields of application. The issue of cost versus personalisation also needs to be considered. There is a real opportunity to engage with the public in this domain e.g. evolving craft concept with personalised meaning - ‘I helped make it’.

How is the UK currently positioned to tackle this grand challenge?

The High Value Manufacturing (HVM) Catapult will provide the perfect platform in which this challenge could grow by bringing industry closer to researchers. The UK has a strong manufacturing sector which could be developed further as the challenge evolves. There is also a wealth of engineering design expertise which could be challenged to think about new research questions whilst considering societal needs carefully from the beginning.

What might be needed to help solve the Grand Challenge?

Materials research will be needed – new technologies might mean materials are used in new ways or need to be replaced and the research community need to be ready for that change. This could be done through a network involving researchers, industry and other stakeholders who need to communicate effectively to identify clear goals under this over-arching challenge. There is also a need to develop novel manufacturing methods (distributed, small scale, on-demand manufacturing) and novel design methodologies.

A more open approach to engineering modelling is also required – this would include software and not having to redesign things that should already be in the public domain. Research into new methodologies and more investment in training will be needed as the engineering solution has to adapt to the users’ needs. A multi-disciplinary flagship project might serve as a model to present the potential this challenge has to offer. There is significant overlap between this grand challenge and the ‘Engineering From Atoms to Applications’ Grand Challenge.
4.5 Big Data for Engineering Futures

Description

Create an environment in which data can be collected, processed and used smartly; this would enable engineers and scientists in a wide range of disciplines to manage data in a robust, reliable and efficient way. Areas in which this might be relevant are Smart Infrastructure, Smart Homes, Smart Health, Smart Cities and Smart Instruments; this list could be expanded to many more fields as new data acquisition models develop.

Sub challenges within this challenge may focus on:

- Sensors: Robust, low power, 24/7, real time sensing
- Reliable, efficient acquisition; storage, transmission and organisation of sensed data
- Accessible (open) information generation in real time and visualisation
- Use of knowledge: how can this data be used to design new interventions or models, control and optimise systems, as well as automate physical intervention
- Some sub-themes might be specific depending on the use of the data (e.g. infrastructure, healthcare technologies)

Who needs to be involved?

The people who need to be involved need to have the end user in mind – these might not be data experts – so a dialogue between the people at each stage of acquisition, processing and output needs to be developed:

- Acquisition – sensor experts, electrical, material engineers, imaging experts
- Data Processing – computer Scientists, machine learning experts
- Users – this would vary depending on the nature of the problem

In addition, social scientists will have to be involved to understand behaviour and the ethical issues surrounding data acquisition, as will cyber-security experts to make sure data is safe.

Pluses and Potentials

The interdisciplinary nature of research and involvement of the end user from the start can help making technology more inspiring and take a more integrated approach moving forward. It can help move smart technology agenda forward (e.g. smart cities require big data if they are to become a reality); it can have societal impact by enabling people to make their decisions with more useful information available.
Concerns and Opportunities

Many of the concerns around this challenge relate to data safety – especially after recent data leaks – this will require taking public’s concern into account when considering how to take the technology forward as well as developing an ethical framework. This could be a very positive technology but needs to be communicated effectively.

Another possible concern is industry walking away from the “smart” technology; some automated manufacturing in the automotive industry has brought people back; this challenge must therefore adapt so that the data infrastructure created is resilient to change and can be adapted and become integral part on how the industry works.

How is the UK currently positioned to tackle this grand challenge?

The UK has a strong set of the core skills although these are currently scattered in different disciplines. There is also a strong sensor development community which is very active in research and industry engagement. The telecoms expertise and machine learning can also be used to tackle this challenge, although again this relies on bringing people together so that a common language is used. Strong computing facilities especially in HPC can facilitate the work.

What might be needed to help solve the Grand Challenge?

Stronger collaboration and interaction will be essential in order to address this challenge – this could be a multi-institutional network bringing in expertise across the engineering community and incorporating social scientists as well as computing experts. The development of open hardware and software for the data processing to be processed in seamless and coordinated manner which is transferable across disciplines would enable big data to become more of tool.

The development of demonstrators to show the power smart data might have on everyday life would be helpful in explaining to society the true benefits if this challenge were solved. This could also be used to explain to the end users, in industry or government, the impact that correct data processing can have, through the use of clever sensing technology, and how interventions can be designed to make life easier.

Contacts from Retreat

Nathan Brown, Ken Grattan, Alison Noble, Dragan Savic, Mark Savill
4.6 Suprastructures – Integrating Resource Infrastructures under Constraints

Description

Design the development and operation of optimised integrated infrastructures - both the physical and organisational structures/facilities - for an uncertain but sustainable future.

As we move to uncertain but increasingly tight resource constraints, how should we design, operate and bring about connected, integrated and holistic infrastructures for communications and information, water, energy, food, material and people to achieve resilience against environmental change, demand variation and technology evolution?

The challenge should aim to make infrastructure truly sustainable and resilient.

The uncertainty that faces our infrastructure in these scenarios means there are a number of sub themes all of which are interlinked:

• Expand the definition of infrastructure to include resources and food and ensure it is thought to be system of systems
• A holistic (national or city) approach that integrates all the different components of infrastructure
• Linking this challenge to others such as Big Data; Complex Systems and Engineering and Society
• Need to define resilience – the infrastructure needs to be adaptable for this uncertain future thinking about external factors – variable demand, population change, new technologies, climate change and others that emerge
• Manage risks by having proper planning and support and avoiding lock-in to specific technologies that would hamper infrastructure versatility

Who needs to be involved?

This challenge is multidisciplinary and will require the involvement from a diverse set of researchers and users:

• Engineers: Civil, Transport, Information Systems, Material Systems, energy and water
• Economists and Social Scientists: micro and macros economics, Business Studies, policy studies, law, geography, urban planners
• Government – over 6 departments could be interested in this challenge: Treasury, BIS, DEFRA, DECC, DCLG, DfT and also local government
• Business: Construction, transport, vehicles IT Systems
• Users: Society (the public); NGOs, lobby groups
Pluses and Potentials

This is a broad and inclusive challenge that can truly address sustainability by having all areas of infrastructure working together. It also fits with other challenges such as Complex Systems and Big Data. Resource efficiency is becoming more important – so infrastructure must become efficient too.

Concerns and Opportunities

The need to properly communicate the value of infrastructure has been one of the barriers for many years in moving this forward; until that has not be addressed the more integrated approach will not be truly considered – this could be seen as an opportunity to reinvigorate this global grand challenge. The opportunity to influence policy makers who will have the ultimate say should also be something to be considered when linking this with the societal benefits of improved, sustainable and efficient infrastructure.

How is the UK currently positioned to tackle this grand challenge?

There is a great deal of expertise in the specific areas of this challenge; EPSRC has a diverse portfolio in Energy Demand, Smart Infrastructure, Infrastructure Systems, water, resource efficiency and living with environmental Change (Sustainable Urban environments and Adaptation and Resilience to Climate Change Programmes); there is also research activity in looking at the economic value of infrastructure both at local and national scale. This challenge provides the opportunity of linking all these research programmes and addresses the underlying infrastructure systems behind them.

Government initiatives both at local, national and global scale are pushing this agenda forward; including Smart/Future Cities, Building Information Modelling (BIM) catapults (Future Cities, Energy, Transport) and Industrial strategies in Construction and Energy as well as Infrastructure UK. This is complemented by activities undertaken by the Professional Bodies including RAEng, IStructE, ICE, IET, CIHT…

What might be needed to help solve the Grand Challenge?

Need for researchers to set and work towards a unified agenda – this could be achieved through a “network +” that would allow the community to work together towards this common goal and allow for interconnectivity between each strand. This can provide a forum for research and practise to come together and discuss the future issues – one of the aims should be to influence industrial strategies and potentially creating a new one around Infrastructure. Future scenarios need to be thought in advance (e.g. Future Cars, roads…) and how infrastructure can be made resilient and adaptable to these changes.

Integration with other Challenges such as Big Data, Complex engineering systems and Engineering and Society is essential to meet the goals. The data that is being generated around infrastructures need to be process and made understandable to be able to inform future interventions. Public outreach will be essential to ensure the future is communicated appropriately and we are not overly reliant on a single technology thus making the future more resilient.
Contacts from Retreat

Julian Allwood, John Nelson, Deborah Pullen, Dragan Savic

4.7 Engineers at the Heart of Public Decision Making

Description

In order to enable engineers to be at the heart of public decision making, a step change in the current culture of engineering education will be necessary. This can only be achieved through greater connection and integration with other disciplines (e.g. economics and politics), by re-framing engineering within the context of social challenges tackled by engineers, and by emphasising the creative rather than manual aspects of engineering. This could involve interventions at a number of levels, including embedding engineering in the national curriculum, combining communication and influencing skills with engineering education at an undergraduate level, and facilitating co-education of engineering and arts students to enable them to discuss the societal impact of engineering. At a public level it would involve communication of the roles and impacts of engineers, including the realities of working as an engineer.

Who needs to be involved?

Work in this area will require the co-ordination of a number of partner institutions, including the EPSRC, the Royal Academy of Engineering, key British industries, and a number of other professional societies and stakeholders.

Pluses and potentials

There is a clear need to attract the best students from schools to study Engineering at undergraduate level, and to both retain and support them through higher and post-graduate engineering. This emphasis on education could also be combined with action to position engineering at the centre of public perception of progress in the UK through increased public and media engagement. Equally it is important that graduate engineers (and applicants to undergraduate engineering) see their role in society in a broad context, emphasising, for example, the roles that trained graduate engineers play in sectors other than engineering e.g. finance, education and the creative industries.

Concerns and opportunities

This work is largely separate to the research agenda although it does link to EPSRC’s Impact focus. Consequently it may be better led by other bodies, with EPSRC playing a key role in partnership. This challenge will need clear drive, direction and a central focus - uniting engineers to tackle it may be challenging but is possible through strong coordination and support. We need to make sure that any new activities add value to work already being done in the area, and don’t duplicate other efforts. However, it is important to embed public engagement, discussion and decision making in general into all aspects of engineering, and vice-versa. It is essential to link innovations and engagement in other Engineering Grand Challenges to this cross cutting challenge.
How is the UK currently positioned to tackle this grand challenge?

There is a clear need in the UK for more work on engagement both with and of engineers, across the breadth of the engineering community. Furthermore, political changes in undergraduate fees may be drawing more students into STEM subjects, and hence this challenge is highly timely and appropriate. Good role models are critical in supporting this Grand Challenge.

What might be needed to help solve the Grand Challenge?

We need to drive this challenge forward in its own right, in order for it not to get lost within the research agenda. Some of the work needed will be to change educational syllabi at all levels, as well as connecting university departments and potential engineering employers to identify pipeline and educational issues. It may be that the identification and sponsorship of individual ‘champions’ is the right approach to taking this forward.

5 Preliminary validation step (post-retreat)

5.1 View from the Engineering Strategic Advisory Team (SAT)

The SAT were given an update at their June 2014 meeting and were asked for their advice on the recent Engineering Grand Challenges Retreat and work undertaken since. The SAT agreed that in working up the plans it was important to engage the wider engineering research community, using the retreat topics as a framework for discussion. On that basis the SAT advised the Executive to proceed with the next stage of the process.

5.2 View from Independent Experts

External members of the research community beyond the EPSRC Engineering SAT were also approached to comment on six of the seven challenges identified and a summary of their views are provided below. Full details of their feedback is available in Annex 9.

Risk and Resilience in a Connected World

This is an on-going engineering grand challenge and is therefore valid. It will always be a complex problem which engineers have to work with. The challenge is broad so more defined sub-themes or sub-challenges will need to be developed, but importantly the underlying connections need to be maintained. Part of the challenge is understanding the nature of the complexity. In many instances engineers work to reduce complexity by finding complicated solutions which are more easily adaptable. This does not necessarily tackle the complexity behind it; this has been particularly apparent in large engineering projects in which costs often end up spiralling out of control. This challenge will require understanding the human aspect of the issues to be tackled as engineers can develop ingenious solutions which cannot work in practise due to human behaviour. This will also require changing the mind-set or hastily developing solutions to meet deadlines and giving greater time for the implementation of new technologies.

‘Living laboratories’ could provide a platform to test models and see how engineering solutions can affect these. A connected world also means that vast amounts of data need to be processed – in this aspect this challenge is linked to that of Big Data for Engineering.
Futures. Appropriate information management tools to handle the emerging understanding of the situation, and the maturing nature of that. Solutions to the problems arising from a connected world might not be apparent so it may be difficult to measure progress - these solutions can only be achieved through multidisciplinary teams.

This challenge fits very well in an international context; there has been funding available for European level and the thinking behind the broader community. It also encompasses many of the underlying challenges faced by the government’s Eight Great Technologies and key UK sectors such as finance, construction or IT. The challenge should remain ambitious but have a set of achievable targets in order to show demonstrable progress.

Potential sub-themes: complexity engineering; modelling of complex systems (theoretical, computational and practical approaches to this); be comfortable with uncertainty and having the tactics to deal with it

Controlling Cell Behaviour

This is a broad challenge which might require further focusing to ensure its goals are not lost along the way. The applications and research fields it may influence are far reaching, most obviously in a clinical aspect, but can be extended to manufacturing and industrial challenges. Cells should be thought of as a collective and the challenge should address how they interact with other systems - these could be electronic, mechanical structures etc. The societal aspects affecting this challenge must also be considered as public perception may be a major hurdle in addressing the challenge.

The challenge has global appeal and there are already initiatives in the US, EU and Asia. It is in line with several of the UK industrial strategies and great technologies. Investment in this area will also be required in order to remain globally competitive. The challenge will inevitably have to develop as policy and further research takes place but it has immense potential – in order to achieve this all relevant stakeholders need to be involved including BBSRC and MRC amongst others – the research challenge can only be solved if the research teams are multidisciplinary and understand each other’s need.,. It is complementary to other challenges such as Big Data for Engineering Futures or Risk and Resilience in a Connected World.

Potential sub-themes: controlling collection of cells; cell interaction with other systems; synthetic biology

Engineering from Atoms to Applications

The research challenge is valid and encapsulates the need to consider engineering problems form the micro to macro scale. The challenge needs to incorporate sustainable approaches to thinking about these types of problems and ensure a whole life cycle approach is taken. Part of the challenge will involve developing robust and efficient multi-scale methodologies which are generic and can be adapted to different engineering problems.

The challenge is framed in such a way it allows for a range of sectors to be involved. Progress in this area could lead to improved resource efficiency and manufacturing technologies. Continued support for researchers working in this area will be essential to
make sure everyone is aware of this overarching theme and there is much chance to collaborate to address the challenge.

*Potential sub Challenges: Designing across scales; manufacturing using advanced material.*

**Bespoke Engineering**

The content of the research is valid but needs to be more focussed and highlight the areas of research opportunities and how these could impact the economy and society. This includes building on the extensive work done in the area from 3D printing or the ‘drug in a bug’ approach to more novel applications such as food processing and agricultural needs. Understanding future needs for this area would be the first step required to flesh out the challenge in more detail.

The challenge is timely and forward looking and there is an opportunity to build on what has already been done in this area. As population centres become more concentrated the concept of bespoke engineering will become increasingly important to enable humanity to adapt to its new and different needs and make the supply chains for products shorter. There is an opportunity to provide bespoke engineering solutions in remote areas or those affected by natural disasters or war.

*Potential sub-themes: Personalised pharmaceutical engineering; readapting supply chain.*

**Big Data for Engineering Futures**

The challenge is seen as very ambitious having broad reach in all fields of engineering and science including areas not mentioned in the document e.g. manufacturing processes and mining. It will require for researchers or teams in this area to be truly multidisciplinary. The challenge does not necessarily lie in generating the data but in linking it together to make it useful. In terms of timeliness this challenge fits very well with UK current priorities and has impact at academic, societal and industrial level.

An opportunity this challenge provides is to stream-line the whole process – firstly develop new sensors and data management systems, then linking and making sense of the generated data and finally adapting this to a range of applications. There are already good examples of new sensor technology being developed at the Cambridge Smart Infrastructure Centre (CSIC). Incorporating big data element to these types of programmes may enable faster market adoption. The process of generating and processing the data is becoming cheaper and less resource intensive and the main challenge lies in ways of automating the interpretation.

*Potential sub-themes: smart infrastructure, smart manufacturing, smart health, novel sensor technology.*

**Suprastructures**

This challenge was very well received – all the experts agreed it was timely and in an area of national and global importance. There was a general consensus that the challenge would need to be specified although the theme was good. The reviewers also thought that links with challenges relating to complex systems and big data would be important to make sure
work is not done in isolation and thoughts from environmental science and ICT should be incorporated into this challenge including societal aspects.

Working alongside government and industry activities should provide a joined-up agenda especially in a time when infrastructure projects are becoming prevalent in many different areas. There are currently a large number of research activities aligned with the Grand Challenge – part of defining it might involve bringing all these researchers together and clarify what is the UK’s unique selling points are and how the research can remain competitive internationally. Next steps may include mapping the current research portfolio in this expansive area and clearly specify the sub-challenge within this theme.

Potential sub-themes: broad connected infrastructure (water, transport, power, etc.), environmental impact on infrastructure

6 Process for getting to the themes

6.1 Input from Universities and Users

In order to provide the retreat attendees with contextual information about what the UK academic research base sees as the key engineering challenges for the future, we sought inputs from all of our framework and strategic partner universities, and our strategic partner stakeholder organisations. Each organisation was asked to identify, from an organisational perspective, up to three major challenges to be met by UK engineering in the years to come, along with an articulation of the importance of the challenge. Below is a summary of the main challenges identified by each organisation:

University of Bath

- Vectors (water, gas, electricity)
- Energy Storage
- Low carbon building materials, energy use and their resilience
- Electrical power applications of high temperature superconductors (HTS)
- Water (including catalysis)

University of Birmingham

- Future planning for the planet, including an integrated approach to water security, energy management and resource efficiency
- Sustainable and efficient energy production (e.g. reliable and cost-efficient offshore wind and tidal energy) and storage.
- Materials design and manufacture, with improved understanding of the effect of both processing and structure on function, especially for materials used in demanding environments
University of Bristol
• Radical innovation in manufacturing of polymer matrix composite structures
• Monitoring, measuring and predicting the remaining life of structures
• Scale up of novel materials

Durham University
• Infrastructure planning under uncertainty and complexity – redesign of infrastructure in the context of decarbonisation.
• Spectrum crunch: How to solve demand for higher data rates in a limited spectrum
• Soil as a resource: Realising the additional potential of soil, returning soils to their pre-industrialised state, and utilising the strength of soils in construction

University of Edinburgh
• Water as a resource and as a threat
• Health security: Assured state of health, and assured response to deterioration
• Sustainable personal mobility

Imperial College London
• Engineering resilient infrastructures
• Engineering products for future generations
• Healthcare challenges of an ageing population

University of Leeds
• Medical Technologies
• Adapting UK Society to Climate Change
• Digital Drug Product Design
• Energy
• Green Energy and Climate Change
• Metals Recovery from Waste
• Sustainable Reduction in greenhouse gas

Loughborough University
• Manufacturing ICT: Realising the manufacturing potential of advances in ICT
• Nature inspired production (wide applications of biomimetics)
• Integrated, smart, low carbon urban spaces – sustainable urban living

University of Manchester
• To provide low carbon, secure and affordable energy
• Advanced materials
• Climate Change

Newcastle University
• Techniques to reduce resource consumption, eliminate waste and mitigate pollution effects
• Step changes in production and process efficiencies so that the natural environment and its resources are safeguarded
• Transform methods used to design, implement and manage our transition towards integrated infrastructure systems such that they better serve the needs of society, and ensure positive interactions with the environment.

University of Nottingham
• Achieving Resilience and Sustainability
• Supporting our ageing population
• Step Change Materials and Manufacturing Technologies

University of Oxford
Energy – with the twin drivers of climate change and security of supply
• Applications of communications and IT
• Applications of technology to healthcare
• Transportation technologies (in the widest sense)

University of Sheffield
• Automated design of high quality inexpensive drugs to fight infection and disease
• Engineering Systems of Systems (design etc.)
• Adapting infrastructure for resilience and uncertainty
• In-silico medicine

University of Southampton
• Resource efficiency (energy and materials)
• Development of a resilient infrastructure
• Clean Water, clean air and clean land

**University of Strathclyde**
• Clean and sustainable energy generation and distribution
• Health
• Environment and Sustainability

**University of Surrey**
• Future Healthcare
• Clean Renewable Energy Provision
• Integrable and multi-functional electronic technologies

**University College London**
• The complete in-silico model of human physiology.
• The embracing cyber-physical design methodology.
• Can we make a big city like London wholly bicycle friendly?
• Could we build a robot to play 'capoeira' - frontiers of affective technology as well as robotics

**Warwick University**
• The advancement of Synthetic Biology (SB) through the development of scalable, robust and biologically compatible design principles.
• There is a national need to invest in resilient infrastructure (e.g. see National Infrastructure plan 2013)
• Predictive Modelling: The challenge is to move computer modelling into the true engineering environment where uncertainty and tolerance must be built in as essential, often safety-critical, features.

**BAE Systems**
• Integrated (Autonomous) Underwater Systems
• Alternatives to Noisy Rotating Machinery
• Effective and Efficient Design, Manufacture and Support of Truly Complex Products
• Safe Launch & Recovery of manned & Unmanned Craft at High Sea States

**Dyson**
• Vision enabled Robotics for unstructured environments
• High power density, portable energy storage
• Surface Engineering

**EON**

• To develop a robust and reliable electricity network for the UK, which has the capacity and flexibility to meet the demands of future energy systems.
• To develop technologies and policies to enable the UK energy system to meet emission targets and adapt to changes to the environment, while delivering an affordable and secure supply of energy to homes and businesses.

**JLR**

• Low Cost Energy Dense Storage
• Smart and Connected

**NDeVr**

• The Challenge is to ensure the secure and safe provision of critical, societal-scale engineering infrastructure upon which a modern industrial society depends for a strong economic future.
• There is a strong imperative to produce long-lasting, reliable, efficient, safe machinery, systems and plant using the minimum of resources throughout the entire engineering life cycles.

**Siemens**

• Affordable near-zero carbon energy and its distribution/storage infrastructure.
• Autonomous, low-embedded-energy transport systems
• Materials efficiency including especially establishment of a circular economy (maximised re-use of manufactured goods and materials, plus recovery and recycling of critical materials)
• Sustainable resources for life – principally water, and (dependent on it) food
• Compact human-like automated systems
• Disease prevention and early diagnosis - screening, imaging, targeted therapy

**Tata Steel**

• The development of intelligent manufacturing (smart factory of the future) for mature manufacturing industry
• Materials development and selection for a low carbon economy
• Cost effective materials in Extreme Environments
6.2 Future Scenario setting – what will the world look like in 50 years’ time?

During the initial session of the retreat, participants were asked to think about possible future scenarios of how the world might look like in 50 years’ time. In order to do this they were asked to think about best, most likely, least likely and taboo scenarios. A summary of their findings follows in table 1 – the complete list is available in Annex 8.5:

<table>
<thead>
<tr>
<th>Best</th>
<th>Most Likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sustainability reached</td>
<td>• Growth/prosperity will still be uneven</td>
</tr>
<tr>
<td>• Most or all disease types can be treated – general good health attained</td>
<td>• Energy is more expensive and rationed</td>
</tr>
<tr>
<td>• Population stabilisation – resource management</td>
<td>• Wars/conflicts will continue</td>
</tr>
<tr>
<td>• Wellbeing of individuals achieved – culturally, economically and health wise</td>
<td>• Big decisions and solutions around problems will have to be implemented – some unpopular</td>
</tr>
<tr>
<td>• Wealth equally shared</td>
<td>• Disease will remain one of the major problems – new types will emerge</td>
</tr>
<tr>
<td>• Exploitation of space (e.g. travel)</td>
<td></td>
</tr>
<tr>
<td>• Poverty and conflicts eradicated</td>
<td></td>
</tr>
<tr>
<td>• Climate Change under control</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Least Likely</th>
<th>Taboo</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Decarbonisation</td>
<td>• Age control – enforced euthanasia</td>
</tr>
<tr>
<td>• Peace – No wars or weapons</td>
<td>• Animal research more widespread</td>
</tr>
<tr>
<td>• Resources are used sustainably</td>
<td>• Big Brother style control of daily lives – privacy non-existent</td>
</tr>
<tr>
<td>• Equality for all</td>
<td>• Genetically engineered humans</td>
</tr>
<tr>
<td>• Robots take over</td>
<td>• Some diseases deliberately not treated</td>
</tr>
<tr>
<td>• Energy available cheaply and sustainably</td>
<td>• New forms of government – democracy no longer seen as best</td>
</tr>
<tr>
<td>• Complete social equality</td>
<td>• Extremism rises</td>
</tr>
</tbody>
</table>

Table 1 – summary of outputs from future scenarios session
The participants were then asked to consider critical factors that might enable or prevent these scenarios; many of these evolved around policy change and the influence governments might have in order to affect these. Technologically, given the right resources and opportunities to put in place appropriate policies, many of the engineering advances identified might be possible. The critical factor to consider in all of this is public perception – the concept of responsible innovation comes into play very strongly here as disruptive technologies can sometimes have unintended consequences. The resources associated with attaining the more ‘positive’ scenarios are significant hurdles to progress.

6.3 PEEST analysis

Following session 1 which focused on future scenario setting, retreat attendees were then asked to think about the current Political & Economic, Environmental, Societal and Technological (PEEST) landscape relevant when thinking of potential future Engineering Grand Challenges. Examples of key findings are summarised in table 2 below. All the outputs from the session are included in Annex 8.6.
<table>
<thead>
<tr>
<th>Political &amp; Economic</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Engineering advice too distributed e.g. no government’s chief engineer</td>
<td>• Energy-food-water nexus</td>
</tr>
<tr>
<td>• No Engineering National Laboratories</td>
<td>• Resources shortage and cost of resources more generally – link to</td>
</tr>
<tr>
<td>• Lack of present inspirational engineers who can inspire the next generation</td>
<td>political instability</td>
</tr>
<tr>
<td>• Focus on impact agenda</td>
<td>• Big data – how to convert masses of data into useful information?</td>
</tr>
<tr>
<td>• Short-term policy making e.g. flooding</td>
<td>• Pollution e.g. oceans, space – how to manage waste more effectively?</td>
</tr>
<tr>
<td>• 30 years decline in manufacturing</td>
<td>• Regulation too often not based on sound engineering knowledge</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Societal</th>
<th>Technological</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Public and media perception of engineering and engineers</td>
<td>What is the UK good at?</td>
</tr>
<tr>
<td>• Skills shortage</td>
<td>• Research &amp; Education</td>
</tr>
<tr>
<td>• Responsible innovation and ethics – how to stimulate public dialogue on key</td>
<td>• Aerospace-related research and innovation</td>
</tr>
<tr>
<td>engineering-related topics</td>
<td>• Advanced materials</td>
</tr>
<tr>
<td>• Diversity – gender imbalance</td>
<td>• High-performance computing</td>
</tr>
<tr>
<td></td>
<td>• Medicines and healthcare</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What could the UK could be better at?</th>
<th>Where might transformative technologies emerge from?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Automotive</td>
<td>• Mobile communications</td>
</tr>
<tr>
<td>• Scale-up and commercialisation</td>
<td>• Infrastructure e.g. transport</td>
</tr>
<tr>
<td>• Physical infrastructure</td>
<td>• Medical devices</td>
</tr>
<tr>
<td>• Electronics/Hardware</td>
<td>• Ubiquitous low-power sensors</td>
</tr>
<tr>
<td></td>
<td>• Quantum technologies</td>
</tr>
</tbody>
</table>

Table 2 - PEEST analysis
6.4 From scenarios to themes - building towards the Engineering Grand Challenges

Key themes arising from the previous sessions (future scenarios, PEEST), as well as from the inputs provided by the Universities and Strategic Partners (see 6.1), were listed. Attendees were then asked to discuss these, add any missing themes from the list, cluster specific areas, as appropriate and finally discuss specific ongoing barriers for each of them (Technological, Integration, Societal, Methodological). The outcomes from this session are available in Annex 8. The themes identified were used as a backdrop from which the Grand Challenges emerged in discussion on Day 2 of the retreat.

7 Conclusions and next steps

Seven areas have thus far been identified as potential Engineering Grand Challenges: Risk and Resilience in a Connected World; Controlling Cell Behaviour; Engineering from Atoms to Applications; Bespoke Engineering; Big Data for Engineering Futures; Suprastructures – integrating resource infrastructures under constraint; Engineers at the Heart of Public Decision Making.

Experts from across the engineering disciplines, as well as the Engineering Strategic Advisory Team (SAT), were asked for their views – the consensus is very clear: the Engineering Grand Challenges themes identified are all valid. However further work is required to identify sub-challenges, milestones and targets and this can only be done in partnership with the research and user community. As a first stage we will convene a small high-level group to reflect further on the outcomes of the retreat, where necessary refining the number of challenges and their content.

Following this and In order to build momentum around the Engineering Grand Challenges, we intend to run three regional workshops in the Autumn so as to:

- Engage the research and user community to identify clear targets or milestones for each of the selected Grand Challenges areas,
- Start the process of building collaborations and/or consortia as appropriate,
- Build advocacy for the Engineering Grand Challenges.

EPSRC is committed to build on the outputs from the retreat, continue to validate them and act in partnership to take the most promising ideas forward.
## 8 Annexes

### 8.1 Annex 1 - Agenda

**Day 1 – 7th May (Chair: Prof Sir Peter Gregson – Cranfield University)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9am</td>
<td>Registration</td>
</tr>
<tr>
<td>9.30am</td>
<td>Introduction to the retreat</td>
</tr>
<tr>
<td>9.40am</td>
<td>Keynote presentation - A perspective on Engineering Grand Challenges</td>
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<td></td>
<td>Lord Alec Broers (House of Lords Science and Technology Committee)</td>
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<tr>
<td>10.15am</td>
<td>‘Getting to know you’ session</td>
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<tr>
<td>11am</td>
<td>Break – Tea &amp; Coffee</td>
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<tr>
<td>11.15am</td>
<td>Session 1 - Scenario setting – What will the world look like in 20-50 years’ time?</td>
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<tr>
<td>12.45pm</td>
<td>Lunch + networking</td>
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<td>1.45pm</td>
<td>Session 2 – The ‘here and now’ – PEEST Analysis</td>
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<td>2.30pm</td>
<td>Session 3 – Themes identification</td>
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<td>4pm</td>
<td>Market place (with Tea &amp; Coffee)</td>
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<td>4.30pm</td>
<td>Session 4 – Engineering Grand Challenges Discussion (Part 1)</td>
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<td>5.30pm</td>
<td>Free time</td>
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<td>6.30pm</td>
<td>Presentation – Responsible Innovation in Research</td>
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<td></td>
<td>Prof Paul Younger (University of Glasgow)</td>
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<td>7.30pm</td>
<td>Retreat dinner inc. pre-dinner speech from Prof Phillip Nelson, CEO of</td>
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**Day 2 – 8th May (Chair: Dr Kedar Pandya – Theme Leader for Engineering, EPSRC)**

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<thead>
<tr>
<th>Time</th>
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<tbody>
<tr>
<td>9am</td>
<td>Keynote presentation – The Chemistry Grand Challenges</td>
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<td></td>
<td>Prof Paul Raithby (University of Bath)</td>
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<tr>
<td>9.45am</td>
<td>Recap from Day 1 + Plan for Day 2</td>
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<tr>
<td>10.15am</td>
<td>Session 4 (continued) – Engineering Grand Challenges Discussion (Part 2)</td>
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<tr>
<td>11.30am</td>
<td>Market place (with Tea &amp; Coffee)</td>
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<td>12.30pm</td>
<td>Lunch + networking</td>
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<td>1.30pm</td>
<td>Session 5 – Challenges prioritisation</td>
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<td>3pm</td>
<td>Feedback session and group discussion</td>
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<td>3.45pm</td>
<td>Conclusions and Next Steps</td>
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### 8.2 Annex 2 - Participants

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<th>Title</th>
<th>First Name</th>
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<tr>
<td>Prof Sir</td>
<td>Peter</td>
<td>Gregson</td>
<td>Cranfield University</td>
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<tr>
<td>Lord</td>
<td>Alec</td>
<td>Broers</td>
<td>House of Lords S&amp;T Committee</td>
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<td>Prof</td>
<td>Philip</td>
<td>Nelson</td>
<td>EPSRC - CEO</td>
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<td>Prof</td>
<td>Paul</td>
<td>Raithby</td>
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<td>Prof</td>
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<tr>
<td>Prof</td>
<td>Sarah</td>
<td>Spurgeon</td>
<td>University of Kent</td>
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<tr>
<td>Dr</td>
<td>Guy</td>
<td>Bart</td>
<td>Imperial College London</td>
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<tr>
<td>Prof</td>
<td>Dragan</td>
<td>Savic</td>
<td>University of Exeter</td>
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<td>Dr</td>
<td>Claire</td>
<td>Adjiman</td>
<td>Imperial College London</td>
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<tr>
<td>Prof</td>
<td>Julie</td>
<td>Yeomans</td>
<td>University of Surrey</td>
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<tr>
<td>Prof</td>
<td>Kevin</td>
<td>Potter</td>
<td>University of Bristol</td>
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<tr>
<td>Prof</td>
<td>Julian</td>
<td>Jones</td>
<td>Imperial College London</td>
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<td>Dr</td>
<td>Andrew</td>
<td>Bayly</td>
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<tr>
<td>Prof</td>
<td>Jason</td>
<td>Reese</td>
<td>University of Edinburgh</td>
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<td>Prof</td>
<td>Julian</td>
<td>Allwood</td>
<td>University of Cambridge</td>
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<td>Prof</td>
<td>John</td>
<td>Nelson</td>
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<td>Dr</td>
<td>Nathan</td>
<td>Brown</td>
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<td>Prof</td>
<td>Ken</td>
<td>Gratton</td>
<td>City University</td>
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<tr>
<td>Prof</td>
<td>Alison</td>
<td>Noble</td>
<td>University of Oxford</td>
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<td>Dr</td>
<td>Deborah</td>
<td>Pullen</td>
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<td>Prof</td>
<td>Mark</td>
<td>Savill</td>
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<tr>
<td>Dr</td>
<td>Kedar</td>
<td>Pandya</td>
<td>EPSRC</td>
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<tr>
<td>Dr</td>
<td>Anna</td>
<td>Angus-Smyth</td>
<td>EPSRC</td>
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<tr>
<td>Dr</td>
<td>Roger</td>
<td>Singleton-Escofet</td>
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<td>Dr</td>
<td>Nico</td>
<td>Guernion</td>
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<tr>
<td>Ms</td>
<td>Sue</td>
<td>Carter</td>
<td>EPSRC</td>
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8.3  Annex 3 - Inputs from Universities and Strategic Partners (Users)

University of Bath

CHALLENGE ONE:

• What is the Engineering Grand Challenge?

Vectors (water, gas, electricity)

• Why is it important?

We have put a lot of research effort into electricity vectors but not into gas or water which are extremely valuable resources. In the area of water vectors we have water utility companies that manage their own ‘grand challenges’ and so it would seem appropriate to look at water holistically. The same can be said of gas.

• How is the UK Research Community positioned to tackle this Grand Challenge?

We would say very well given the emergence of a number of CDTs especially in the water area.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

All disciplines as there is a significant customer engagement activity here as well as infrastructure, resilience and future sustainability with what we consider to be a major policy driver. There are also many aspects of ‘big data’ that underpin this grand challenge.

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

Energy storage

• Why is it important?

It underpins a significant multidiscipline science driven research base in the UK and we should be looking to be more over the horizon driven with regard to emerging technologies or indeed technology that needs to advance as in superconductivity

• How is the UK Research Community positioned to tackle this Grand Challenge?

Very strong but the community needs to be wider in scope and more inclusive

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

It’s difficult to see which research disciplines you would leave out as we have the fundamental research and the application driven side and a recent example of this is the BIS APC. Energy storage will be crucial to reducing the carbon footprint of future automobiles.

CHALLENGE THREE:
What is the Engineering Grand Challenge?
Low carbon building materials, energy use and their resilience

Why is it important?
Buildings are still a large part of our energy consumption, are we doing enough to reduce it?

How is the UK Research Community positioned to tackle this Grand Challenge?
Strong but strong, larger and more diverse groups need to be brought together to tackle problems in an holistic manner

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?
Built environment, planning, architects and the science community at large.

University of Birmingham

CHALLENGE ONE:

What is the Engineering Grand Challenge?
The grand engineering challenge of this century is how to enable nine billion people to live well within the confines of a single planet, given that we have drained it of easily extractable mineral and energy resources, polluted vast areas of land and water and are dealing with a changing climate that brings further threats to food and water security. In short, the industry lacks a cohesive, integrated approach to water security, energy management and resource efficiency.

Why is it important?
Moving towards a resource efficient economy is vital to secure the resources required to fuel the global economy and feed the global population. The threats to water, mineral, energy and food security are now being recognised at an international level and there is a considerable groundswell of political interest that is focusing attention and funding on the research required to move the world towards a resource efficient economy. It is water that binds the food, energy, climate, economic and human security challenges we face in the future. Without enhanced knowledge of water security and resource efficiency (including (bio-) energy, nutrients, etc.), our adaptation measures will have limited success, and so will our ability to survive. Achieving global water security and resource efficiency requires systems-based thinking, and systems are by their very nature complex and multidisciplinary, requiring researchers to understand the fundamental technological, environmental, economic and social issues at hand. Yet there remains major scope for improvements in our understanding of the science which underpins our technological solutions, and there remains much work to be achieved in the complementary management of water, energy and food. We lack detailed fundamental scientific information and understanding at the process level, and we lack overall quality and energy management strategies at the holistic level.

How is the UK Research Community positioned to tackle this Grand Challenge?
The UK Research Community possesses the skills base required to address this challenge, but in a fragmented way. Whilst there are some excellent research groups, there remains the need for a coherent approach which places a unified strategic focus on these issues. In particular, there is a need for a focus to be placed on experimental and numerical approaches to address the challenges which we face in managing water security and resource efficiency and the associated links with energy management.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Chemical engineering, civil engineering, environmental engineering, (bio)chemistry, applied mathematics, electrical engineering

**University of Bristol**

**CHALLENGE ONE:**

- **What is the Engineering Grand Challenge?**

To drive radical manufacturing innovation to create the next generations of polymer matrix composites structures that truly exploit the full potential of the material class in terms of minimal weight, maximum production rate and sustainability.

- **Why is it important?**

Progress in the field has been largely incremental and held back by limitations on aspiration. Projected massive growth in demand for composite structures cannot be met without a serious challenge to established practices, and introduction of radically new solutions.

- **How is the UK Research Community positioned to tackle this Grand Challenge?**

Recent national investment has made a step change in our ability to address challenges in design, analysis, machine and material developments to underpin the challenge.

- **From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?**

Engineering; Materials Science; Chemistry; Machine design & robotics; Manufacturing

**CHALLENGE TWO:**

- **What is the Engineering Grand Challenge?**

Monitoring, measuring, predicting the remaining life of structures - i.e. the ability to go to an unknown structure and diagnose its remaining service life (as cheaply and effectively as possible)

- **Why is it important?**

The UK infrastructure is ageing and better monitoring could enable us to extend its life (power generation is a great example). The National Infrastructure Plan identifies £380bn of infrastructure renewal needs. Many tens of billions of value could potentially be
achieved/saved by extending the life of existing infrastructure. It is also an environmental issue to get the most out of the engineering structures we create. There is the potential to move to structures that can diagnose their own health and send the results back to HQ. There is an urgent need for a risk based, generic framework for life extension based on a systems approach that enables us to capture generic lessons and apply them to specific infrastructure cases. Technical developments will only have industry impact if they also establish a compelling business/investment case.

- How is the UK Research Community positioned to tackle this Grand Challenge?

Perfectly, for e.g. the UK NDE centre for example. But this is a paradigm shifting concept so need funding for highly adventurous work in this area (RCNDE is a joint EPSRC‐industry centre). The UK has expertise in infrastructure systems, design, risk and hazard research, with expertise that spans nuclear, bridges, dams, utilities, and manufacturing. New measurement technologies are also needed and this will need collaboration with other field, such as Physics.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

All types of engineering as well as Physics, possibly computer science and mathematics.

CHALLENGE THREE:

- What is the Engineering Grand Challenge?

To take developments in materials, for example nanoscience, and dramatically up-scale them - i.e. take these now materials to the point where they are of use in engineering structures and components .i.e. build an aeroplane of nanomaterials.

- Why is it important?

There is huge value to be had by taking these new materials further up the development chain. Ultimately this is where business can step in (as there is clearly money to be made). But as things stand a lot of what is done in new materials either dies a birth as its irrelevant or gets taken up by other countries. We (the UK) needs to do this more applied work (i.e. add the value) as well, and it needs to involve engineers (as opposed to scientists).

- How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has a strong presence in nano and materials, so there are good opportunities here. But we need a new breed of nano-engineers to add the value to the nanoscience.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

All types of engineering, particularly mechanical/aero and civil
Durham University

CHALLENGE ONE:

• What is the Engineering Grand Challenge?

“Infrastructure planning under uncertainty and complexity”

With the need to decarbonise economies worldwide, all major infrastructure networks will need to undergo significant redesigns. This affects electricity networks directly (in terms of the need to integrate emerging generation technologies), will also affect other energy networks which interact directly with electricity (e.g. changing demands on gas networks, development of heat networks), and will mean major changes to transport networks as well (in terms both of expansion of capacity of e.g. long distance rail, of electrification being the primary means of decarbonising transport). Overlaid on this is increased interaction between communication networks and other infrastructure, e.g. the smartgrid concept for energy systems.

• Why is it important?

Decarbonisation is one of the major challenges facing today’s society, and will require major changes in both infrastructure and the way which society interacts with energy and transport systems. The huge infrastructure programmes required, combined with the inevitable complexity of decision support tools required to facilitate systematic coordinated planning of different infrastructure networks, represent huge engineering and analytical challenges.

• How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has very considerable strengths in energy systems modelling (Supergen, wholeSEM, etc), in other network infrastructure (e.g. the RCUK Digital Economy theme), and in required general modelling methodologies (e.g. control, and the Managing Uncertainty in Complex Models community). The UK is thus well placed to make a distinctive world leading contribution in this field.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Engineers and economists – who have specialist knowledge of the infrastructure, and of the market and regulatory context in which it sits.

Control engineers/mathematicians – to design algorithms to run these more complex interacting networks.

Statisticians – to understand the relationship between the complex computer models built to support planning decisions, and the real systems which they are intended to represent.

Social scientists – to understand the effects on society of changes in infrastructure, and to understand how people may interact with changing infrastructure

CHALLENGE TWO:

• What is the Engineering Grand Challenge?
“Spectrum crunch”

Demand for higher data rates in limited spectrum poses a grand challenge for regulators and network providers. Techniques to tackle this challenge include: in the lower frequency bands (1) shared spectrum or re-farming of current licenced spectrum, and (2) spectrum aggregation; alternatively use of higher frequency bands (mm Wave between 20-100 GHz) where large spectrum is available.

• Why is it important?

For the lower frequency bands:

1. Accurate 3D propagation models for data base approaches of cognitive radio
2. Low cost radio frequency devices and systems for agile sensing and spectrum aggregation
3. Signal processing for sensing and massive multiple antenna techniques

For the mm Wave band

4. Understanding of the radio channel.
5. Appropriate propagation models for cell design and coverage in heterogeneous networks
6. Radio frequency devices for the mm wave mass market
7. Antenna design for beam-forming
8. Network planning

• How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has researchers active in these areas; with some EU funding and some HEFCE funding. To address this grand challenge investment by EPSRC would be needed for both PhD students and via special calls.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

RF (Radio frequency) engineering, Communications engineering, Radio science/engineering, Signal processing

CHALLENGE THREE:

• What is the Engineering Grand Challenge?

“Soil as a resource”

Topsoil and subsoil form a huge resource, in which we grow our food and found our buildings and structures. The grand challenge is to realise the additional potentials of soils, for instance to act as a carbon sink of massive proportions, and to form the raw materials which could replace carbon-heavy cement-based materials for construction. We need to
return soils to their pre-industrialised state, capable of providing ecosystem services such as carbon sequestration, food production and flood mitigation. We also underutilise the strength of soils and better understanding could unlock major savings in construction. Bio-additions could provide further means of designing properties into soils (mechanical, hydraulic, etc.)

- Why is it important?

We will not be able to feed the growing global population without restoring soil health. In addition, One third of all global greenhouse gas emissions to date are from soils and we need to engineer the soil to become the carbon sink that it used to be. 5% of all Man’s production of CO2 is directly linked to cement production (not even including its use) so it is remarkable that we are not trying our best to reduce consumption through alternatives, e.g. soil structures which utilise inherent strength currently ignored.

- How is the UK Research Community positioned to tackle this Grand Challenge?

EPSRC-funded initiatives such as LIMESNet have been a refreshing change, bringing together a wide range of researchers under a single banner, and the projects that have been funded arising out of this and the other funded network are exciting and forward-looking. We would hope EPSRC continues in this vein.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Engineering, Earth Sciences, Material Science, Geography, Environmental Science, Chemistry.

**University of Edinburgh**

**CHALLENGE ONE:**

- What is the Engineering Grand Challenge?

Water as a resource and as a threat

- Why is it important?

Human life and comforts demand large volumes of clean, safe water, but supply is at risk. Our marine environment also offers large-scale supply of clean energy. But lack of flood defences threatens our infrastructure.

- How is the UK Research Community positioned to tackle this Grand Challenge?

Well - many excellent hydrodynamicists, mechanical, electrical and civil engineers.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

As above.

**CHALLENGE TWO:**

- What is the Engineering Grand Challenge?
Health security: assured state of health, and assured response to deterioration

- Why is it important?

Growth of the elderly population presents a potentially huge burden to society and to health services, greatly exacerbated by emergency events. Continuous monitoring of many key measurables in the human body will become commercially available, but this will generate demand from lower-risk sections of society, e.g. starting with the “healthy elderly”, who have growing political power. Quality of life for longer will be a driving force, exploiting the “Internet of Everything” for the ultimate human benefit.

- How is the UK Research Community positioned to tackle this Grand Challenge?

Well, with excellent people in miniaturised sensors, microelectronics, sophisticated and secure communications, informatics.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

As above.

CHALLENGE THREE:

- What is the Engineering Grand Challenge?

Sustainable personal mobility

- Why is it important?

For over a century, more and more of the global population has grasped with relish the opportunities afforded by personal transport, mainly by private car. This is under threat from the CO2 imperative, demanding greater specific fuel efficiency, a broader range of fuel types such as recycled biomass, wider propulsion options (e.g. electric motors as well as combustion engines), CO2-efficient cycles for electrically powered vehicles.

- How is the UK Research Community positioned to tackle this Grand Challenge?

Well - excellent breadth in the mechanical, chemical and electrical specialisms that will all be necessary.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

As above.

Imperial College London

CHALLENGE ONE:

- What is the Engineering Grand Challenge?

Engineering Resilient Infrastructures
Sub-themes include:
- resilience of energy supply
- resilience of water supply (including context of climate change)
- engineering resilient urban systems.

- Why is it important?

Modern societies depend on the effective and reliable operation of infrastructure systems to deliver energy, food, water, sanitation and transportation. The effectiveness of these services is however increasingly challenged by geopolitical uncertainties (in the case of energy) and unpredictable and more extreme weather conditions (in the case of food, water and transport). Moreover, these changes take place against a backdrop of global population growth and increasing urbanization.

Within the energy sector we need to develop resilient energy supplies and delivery networks to meet the needs of both citizens and corporate consumers. Critical challenges include:

- Creating the future form of a gas system using varied sources such as biogas and fracking gas especially understanding and managing associated environmental and other risks.
- Creating infrastructure in energy networks that combines sources in a resilient fashion and allows source switching for short-term and long-term risk reduction and ability to cater for substantial changes in energy use.
- Developing nuclear technology that has technical characteristics and scale that mitigate financial and technical risk.
- Analysis and modelling of technical risk including extreme (high-impact, low-probability) events.

Within the water sector, major challenges exist in the following areas:

- Prediction and management of the occurrence and impact of flood and drought events
- Impact of climate change on the quantity and quality of water resources and ecosystems
- Real-time monitoring and optimal use of water infrastructure
- Enhancing the sustainability of urban areas by integrating the design and management of water, energy and infrastructure systems.

In the area of urban systems, major challenges include:

- Understanding the interactions and vulnerabilities amongst multiple inter-dependent physical and cyber urban infrastructures
• Characterisation and treatment of multiple sources of uncertainty in all stages of the urban infrastructure lifecycle including planning, design, funding and financing, construction, commissioning, operation, maintenance, repair/renewal, decommissioning

• Engineering for active urban citizenship including the design of infrastructure and services that enable citizens to maximise their potential as producers, consumers and innovators

• Cross sectoral system identification, prediction and control at multiple temporal and spatial time scales

• Engineering urban infrastructure to be more resilient to extreme loading.

All of these challenges will require fundamental engineering research and the provision of high level engineering skills.

How is the UK Research Community positioned to tackle this Grand Challenge?

The UK is well positioned to lead research programmes addressing resilient urban infrastructures, with internationally leading groups at Cambridge, Imperial College London, UCL, Reading and Loughborough Universities. However, this community is not well funded, with only 6.2% of the EPSRC budget currently spent on research in the Built Environment area, and a further 1.7% on Coastal and Waterway Engineering.

http://www.epsrc.ac.uk/research/ourportfolio/themes/engineering/Pages/researchareas.aspx

The UK also has an internationally leading research activity in geotechnics, which will provide critical underpinning research for the development of more resilient underground infrastructures and will be important for the expansion of fracking in the UK. The recent launch of a CDT in Sustainable Civil Engineering (Imperial College) will help to fill the gap in PhD level training in this area.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Engineering resilient infrastructures will require expertise from all Engineering disciplines.

CHALLENGE TWO:

What is the Engineering Grand Challenge?

Engineering Products for Future Generations

Why is it important?

A vital and dynamic manufacturing base is an essential component of a sustainable economy. While manufacturing has recently received much attention within BIS, and several sectors, notably aerospace, defence and pharmaceuticals, are extremely successful and enjoy world-wide reputations, the UK’s underlying technology base that will be the foundation of future generations of products is patchy and poorly supported. The initiatives on Graphene and Quantum Technologies are welcome, but these areas are limited by their
specific technology focus and they will require many years of sustained research and development before economic returns are realised.

The aim of this challenge is therefore to harness the UK’s highly productive research base in physical and life sciences and combine it with our outstanding engineering capability to create the products, processes and services that will form the basis of future economic growth.

We propose that EPSRC launch a strategic initiative on engineering products for future consumers, with the following aims:

• Transform advances in fundamental engineering science and materials research into future products for consumers and for industrial application

• Combine the expertise of leading engineers with practitioners in design and innovation to produce products that excite and inspire future generations

• Educate and inspire a new generation of engineers to acquire skills in design and innovation, enabling the translation of advances in fundamental research into everyday products.

How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has an excellent base of researchers across the broad range of fields that will provide technologies underpinning products of the future, from engineering to physics, chemistry and materials science and computational modelling. Within Manufacturing research, the EPSRC has an extensive and well established network of Centres for Innovation Manufacturing, but they largely focus on current technologies, rather than those that will form the basis of future products and processes. The UK also has an internationally leading capability in enabling technologies such as Additive Manufacturing (https://www.raeng.org.uk/news/publications/list/reports/Additive_Manufacturing.pdf).

The UK’s innovation system, supported by initiatives led by BIS and TSB (and Horizon 2020 within a European context) is well placed to take advantage of new ideas and technologies emerging from the engineering and science and engineering base. All leading engineering and science based institutions have well developed technology transfer structures that can pilot new ideas through the innovation process and engage with industrial partners and VC financing.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

The challenge combines expertise from engineering with fundamental science and so researchers will need to be drawn from across these disciplines. The inclusion of expertise in product design and innovation will also be critical to success.

CHALLENGE THREE:

What is the Engineering Grand Challenge?

Healthcare challenges of an ageing population
Why is it important?

The ageing population is a stark challenge facing developed countries such as the UK. The percentage of persons aged 65 and over increased from 15 per cent in 1985 to 17 per cent in 2010, an increase of 1.7 million people, and is projected to increase to 23 per cent by 2035 [ONS]. The number aged 85 and over has more than doubled from nearly 0.7 million in 1985 to reach over 1.4 million in 2010.

The burden of chronic diseases of ageing is increasing rapidly as the population ages. The risk of dementia rises sharply with age with an estimated 25-30% of people aged 85 or older having some degree of cognitive decline [WHO]. Osteoarthritis afflicts 8.5 million people in the UK, 71% of whom are in constant pain and over 1 million of whom say their pain is often “unbearable”. The incidence of Osteoarthritis is predicted to double to 17 million by 2030 [OANation 2012 Survey]. Other chronic diseases of ageing, such as cardiovascular disease and cancer are also increasing.

The ageing population and associated diseases is imposing a profound burden, not just on healthcare systems, but more widely on society. The Health Survey for England in 2012 found that among people aged 65 and over, more than a third of women (36 per cent) and just over a quarter of men (27 per cent) reported a need for help in the last month with at least one Activity of Daily Living. Many require some form of long-term care, which can include home nursing, community care and assisted living, residential care and long stays in hospitals.

The healthcare and societal challenge of the ageing population is immense and necessitates a concerted and unified effort, with technologists at the forefront driving innovation to enable people to live healthy, active lives for longer.

How is the UK Research Community positioned to tackle this Grand Challenge?

The UK is ideally positioned to deliver technological solutions to meet the challenges of an ageing population. Innovation for treatment of chronic conditions and assisted living of an elderly population are likely to be based on medical technology rather than pharmaceutical intervention, which presents an important opportunity, as well as a challenge, for the UK.

Given its remarkable heritage in engineering innovation, the UK is uniquely placed to leverage its academic, industrial and clinical infrastructure to deliver transformational solutions for elderly citizens and patients with worldwide impact. At the interface of engineering and biomedical science, the field of biomedical engineering is an emerging area where the UK has the potential to lead on the world stage.

Over the past 20 years Biomedical Engineering has grown from a sub-discipline of engineering to a field in its own right, and it is now poised to shape the future of healthcare. Major UK centres include Imperial College, UCL, Oxford, Leeds and Strathclyde Universities.

With the support of policymakers and RCUK, the UK’s academic and healthcare infrastructure through its leading Universities and Academic Health Sciences Networks, is in a position to discover and develop a vibrant pipeline of technological solutions to meet the challenges of the ageing population. Further investment and collaboration with industry will
also drive the Med-Tech industry sector that is currently dominated by SMEs, allowing it to grow and flourish.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Biomedical Engineers and Bioengineers come from across the spectrum of engineering disciplines, including mechanical, civil and architectural, computing, electronic, robotics and materials, and apply the principles and techniques of engineering to the challenges of biology and healthcare. Fields of note include regenerative medicine, neurotechnology, cancer engineering, musculoskeletal technology, cardiovascular and fluidics, physiological monitoring and biosensing. Major breakthroughs in a number of these fields evidence the potential of biomedical technology to impact diseases of ageing, e.g. pacemakers and stents for cardiovascular disease and orthopaedic implants for osteoarthritis. The burgeoning field of neurotechnology, at which the UK is at the forefront, is set to transform our understanding of dementia and deliver solutions to delay, treat and improve the lives of those affected.

University of Leeds

CHALLENGE ONE: Medical Technologies

Designing, deploying and supporting complex technology-intensive systems that are affordable through-life (for all stakeholders), wanted, usable and used. The systems will be blends of, amongst other things, diverse collections of technology, information, materials, money, people and organisations. Their success will depend on underlying processes and systems such as business processes, innovation systems and supply networks, and human capability, as well as science & technology. Robotics is also a key cross-disciplinary challenge involving Mechanical, Electrical, Computing, Materials, and also associated life sciences such as medicine and the inspiration from biological systems.

What is the Engineering Grand Challenge?

The engineering grand challenge is to provide healthcare solutions at a time when technologies are becoming more sophisticated and the population is ageing, which are cost-effective and which then ensure that the NHS becomes sustainable in the long term. This has to be driven by engineers who can use a multi-disciplinary approach (also involving social scientists, health economists etc) to optimise how technologies are developed to ensure the most cost effective solutions.

How do you design (including predictive tools), develop, deploy and support technology-intensive complex systems that take account of multiple stakeholder needs? How do you evaluate design ideas in a cost effective manner and how do you ensure stakeholders stay engaged in the process? For mechanical engineering, a lot of the challenges relate (or can be traced to) to shape and material.

Healthcare systems are increasingly resource limited, with greying populations, and a moral/ethical need to support developing countries with cost-effective interventions.
Use of science and engineering to support and improve healthcare, specifically surgical interventions. This should span diagnosis (early identification), intervention (cost-effective delivery of treatments which minimise trauma) and recovery (e.g. enhanced rehabilitation).

Why is it important?

The demands on the NHS are becoming unsustainable; the capabilities are becoming unprecedented and technology is at the heart of medical interventions. There is a risk that if this is not properly optimised, in a systematic way, the NHS will struggle to deliver a service that is fit for purpose.

How is the UK Research Community positioned to tackle this Grand Challenge?

Medical technologies are at the heart of much of the pioneering research that is being undertaken in engineering and science departments across the UK. However, cost-effectiveness is rarely discussed as a primary factor. Medical research in engineering schools rarely considers the cost or the benefit until late into the translation process. The grand challenge is to embed this principle early in the research path. As a community we have the scientific foundations and capability to develop science and technology further although more would be good. However, we may have limited capability to apply science to create solutions to societal challenges.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

All – Engineering, hard and soft sciences, design, arts & humanities, business, law, .... For societal challenges one may need to consider how representative of society research teams are too. Eg, better representation and balance of gender, ages, social background, education, life experience, etc.

CHALLENGE TWO: Adapting UK Society to Climate Change

What is the Engineering Grand Challenge?

To design the UK’s infrastructure and society to make it adaptable to the levels of climate change that are now seen as inevitable. This includes energy networks, transport, buildings, water supply, health, to name just a few.

Why is it important?

The recent IPCC report places greater emphasis on Adaptation to Climate Change as opposed to earlier focus on Mitigation of Climate Change. This is based on the acknowledgement that emissions are not reducing at the required rate and significant climate change is inevitable.

How is the UK Research Community positioned to tackle this Grand Challenge?

UK researchers have not only the broad range of skills required to address this challenge, but also the track record of collaboration across disciplines. UK researchers are world-leading in this area as evidence by level of publication, citation and involvement in international projects.
From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

A wide range of disciplines are required: engineering, geography, natural sciences, health sciences, economics, social science and business studies.

CHALLENGE THREE: Digital Drug Product Design

What is the Engineering Grand Challenge?

National Centre for Digital Drug Product Design

Why is it important?

The global medicines industry is in a period of dramatic change. Patient expectations are rising rapidly. They want customised treatments with better results and fewer side effects. Exciting scientific advances bring new opportunities, but also require significant investment. These factors are driving a fundamental shift in how medicines are developed, made and marketed.

In recent months a Ministerial Industry Strategy Group (MISG) has been developing a cross Pharma industry view of the potential investment opportunities within the UK that will help integrate emerging science and technology with medicines manufacturing.

One opportunity identified was to reposition the UK’s capability in small molecule production based on a digital design of product philosophy. Using existing expertise, the UK can translate academic expertise to new design and manufacturing processes for small molecules. In our journey towards a digital definition of drug product design we envisage:

• An unprecedented structural perspective of product design
• Enhanced relationships at the academic/industry interface
• A digital definition of drug product design

How is the UK Research Community positioned to tackle this Grand Challenge?

Our ‘proposal’ is to establish a world-leading centre for the digital design of products to support academia and industry and help accelerate drug product development. This would build on existing government-industry-academia collaborations. This national centre would be a global first and would secure the UK’s position at the forefront of drug product design and development ensuring medicines reach patients faster.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

A range of disciplines and centres would be required, indicatively (with exemplar contact names) for example: The Diamond Light Source (Prof Trevor Rayment); The Cambridge Crystallographic Design Centre (Dr Colin Groom); The Pfizer Institute at Cambridge (Prof Alan Windle); Leeds – Synthonic Engineering (Prof Kevin Roberts); Imperial College γ-SAFT (Prof George Jackson); Process Systems Engineering (Prof Costas Pantelides);
Daresbury Computing Centre (Dr Adrian Toland); CMAC - Strathclyde University (Prof Alastair Florence); Institute for Pharmaceutical Imaging (Prof Morgan Alexander).

CHALLENGE FOUR: Energy

What is the Engineering Grand Challenge?

Addressing the trilemma of energy sustainability, energy security of supply and energy affordability. Achieving any two of these is challenging, tackling all three of these is a profound challenge.

Why is it important?

Effective response simultaneously to: climate change, the UK’s future economic competitiveness and making energy accessible to all.

How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has major strengths in the greening of conventional energy (e.g. CCS), renewables and nuclear. There is also a research community that seeks to connect the engineering and broader aspects of energy (e.g. economics, policy, socio-technical).

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Energy impacts/is impacted by every engineering discipline and many disciplines beyond energy. Hence, it is essential to promote effective interdisciplinary collaboration.

CHALLENGE FIVE: Green energy and Climate change

What is the Engineering Grand Challenge?

There are many potential technologies for green energy but all of these, with the possible exception of next-generation nuclear fission, are not ready for large scale deployment as they need to be made more efficient and cheaper – e.g. solar (such as photocatalysis), nuclear fusion or biofuels.

For climate change, the engineering challenges are energy efficiency, CO2 capture & storage and flood defences.

Why is it important?

Green energy and climate change are inherently linked and it is necessary to tackle these challenges in order to minimise the impact of extreme events such as severe weather, flood/drought and resultant human and economic disasters.

How is the UK Research Community positioned to tackle this Grand Challenge?

The UK generally possesses the quality and diversity of skills to tackle these challenges either within the existing research base or through its ability, (albeit perhaps weaker than in previous decades due to the lower priority given to research in the UK, compared to similar economies), to attract excellent researchers from around the globe.
From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Many disciplines including: physicists, chemists, materials scientists, process engineers and civil engineers will be needed to tackle these challenges.

CHALLENGE SIX: Metals Recovery from Waste

What is the Engineering Grand Challenge?

Providing the UK and UK industry with technologies (for overseas export) that can recover metals from wastes: economically, environmentally safe and easy to implement within SMEs.

Why is it important?

Many wastes (IT, metal refining and extraction, nuclear) contain higher levels of precious and rare metals than the original ores. Significant savings can be made on both disposal and cost of raw materials if these metals could be recovered.

How is the UK Research Community positioned to tackle this Grand Challenge?

Only a few universities (Imperial, Newcastle and Bath) currently have funded projects in this area. There is a close connection with liquid-liquid extraction R&D connected to nuclear engineering (rare earth extraction). A coupling of the two communities on a single challenge programme would put the UK at the forefront internationally.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Engineering – primarily chemical, minerals and mining; Chemistry; Environmental science; Economics/Business studies.

CHALLENGE SEVEN: Sustainable Reduction of Greenhouse Gases

What is the Engineering Grand Challenge?

The sustainable reduction in greenhouse gas (GHG).

Why is it important?

Current methods of reducing GHGs, especially in the electricity supply area, all increase the cost to the consumer. This is politically difficult and routes to low GHG at low cost need to be given more prominence. The challenge is to develop significant improvements in thermal efficiency of processes so that both costs and GHG are reduced.

The automotive industry is showing the way, led by draconian GHG reduction targets from EU legislation for new vehicles. In 2020 the average fleet GHG emissions must be below 95 g/km and this is >50% reduction on the 1990 position. The technology for larger reductions is an area for this project to support.
In electricity supply there has been concentration on renewable electricity to the exclusion of improved thermal efficiency and yet 87% of our total energy still comes from fossil fuels and 66% of our electricity.

The major areas of energy consumption and GHG generation are:

1. Electricity Supply
2. Transport – air, road and sea
3. Domestic and commercial
4. Industrial – heat and electricity
5. Agriculture – the major source of CH4 and N2O (nitrogen based fertilisers)

Cost effective technology is required to be developed that will reduce GHG emissions in all the above sectors. Advanced combined cycle gas turbines currently have 325 gCO2 /kWh compared with the grid average of 450 gCO2 /kWh. Advances in turbine blade and combustor cooling are required to allow higher peak operating temperatures, which controls the advances in thermal efficiency which drive CO2 lower. Thus a key technology is wall cooling using advanced film cooling and impingement/effusion cooling (where Leeds, for example, has a world reputation). Also the problem of increasing firing temperatures in gas turbines means there is an associated NOx problem (again Leeds is a world leader in ultra low NOx GT technology).

A further area of advanced green power is that of concentrated solar gas turbines, which the solar heat flux replaces the combustion heating. These solar GT cycles enable closed cycles with CO2 as the working fluid to be used with higher cycle efficiencies than for air and this should be an area that is developed.

Other technology problems associated with electric power generation is the use of supercritical steam cycles at high pressure both in coal plant and in combined cycle gas turbines. There are associated metallurgical problems with all these advanced power cycles.

For transport, advances are being made in engine thermal efficiency and in on-board storage of energy using batteries charged from reciprocating engines. The design of efficient small engines tuned to operate at one condition for battery charging is the future of passenger car transport. The operation of these on 100% biofuels could eliminate GHG from the transport sector.

In the domestic sector the development of advanced high efficiency biomass boilers for thermal heat is an area that is ripe to be exploited. Better biomass heaters are also required for the thermal heat demands in industry.

A theme that crosses all the application sectors is the need to store energy, as only fossil fuel energy gives power on demand. Storage of energy either thermally (hot water from solar or biomass), in batteries, pumped storage or compressed/liquid air systems all enable surplus renewable energy to be stored instead of being paid not to generate as at present. Battery storage in vehicles is at the heart of low CO2 transport.

How is the UK Research Community positioned to tackle this Grand Challenge?
Most of the technology areas have more than one University actively involved. The transport area through the Low Carbon Vehicle Partnership is already following the technology solution to GHG reduction.

There needs to be a shift of resources to direct GHG reductions from fossil fuels use through improved thermal efficiencies. Many renewable technologies do not reduce CO2, they produce new electricity to feed growing demand for more electricity without increasing CO2 emissions. Improving the thermal efficiency of fossil fuel energy use reduces CO2 directly.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Engineering, Chemistry and materials (batteries), Agricultural Sciences (biomass production), Large scale pumped storage – Civil Engineering

**Loughborough University**

**CHALLENGE ONE:**
- What is the Engineering Grand Challenge?

Manufacturing ICT: realising the potential into Manufacturing of the recent advances in ICT landscape, such as resilient cloud computing and analytics down to lower level semantic hardware to allow manufacturing efficiencies from real time optimised inputs, e.g. resources (people, energy, water, materials). Upstream from this is zero prototype produce development, by means of linking design to semantically enabled manufacturing resources – we call this cyber physical interactions for manufacturing.

- Why is it important?

Manufacturing in the first world has seen concentration on high added value products and processes. However, the game is changing, the drivers are now resource efficiency, rapidity to market, resilience of supply chain etc. The levels of automation and standardised production techniques across the globe are such that labour rates are decreasing in importance. IP in manufacturing will be the discriminator.

- How is the UK Research Community positioned to tackle this Grand Challenge?

We have nuggets of capability in manufacturing and ICT and some linkages already formed, but the scale of the challenge is much bigger than is being supported. We have very good manufacturing academics and very good ICT academics, but there remains a comparative chasm between them.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

ICT
Manufacturing
Design
Economics
CHALLENGE TWO:

• What is the Engineering Grand Challenge?

Nature inspired production - Biomimetics as the new approach to design products, operations, systems, communities, ecosystems, and the manufacture and/or implementation of those new strategies.

• Why is it important?

Nature is by it's very essence a self-optimising entity, we can learn from how nature optimises materials and resources to deliver stuff. We have seen nature being used as the inspiration for many products, e.g. passive air conditioning based on termite mounds, wing design inspired by the aerodynamics of raptors. However, we have not yet explored to any depth, the processes nature uses to create the world around us. There is great potential for more efficient, less resource hungry processes (both human or in terms of production of goods or services) that are better in-tuned with the ecosystem(s) and can offer long term sustainability.

• How is the UK Research Community positioned to tackle this Grand Challenge?

We have excellent life, bio and agri scientists in the UK as well as good manufacturing engineers, many of whom have come from interesting backgrounds. There are other movements in USA and Europe that have looked at product driven nature inspiration, we have an opportunity to jump ahead and becomes the suppliers of future factories. The UK research community has a solid science base and enjoys a healthy pillar of engineering applications. The Scientific base comprises Mathematical sciences (that can help represent and explain which are those benefits to learn from and harness); Biology, Chemistry and Physics (that can help explain why); the engineering pillar shows prowess in design, manufacture and process engineering.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Engineering, manufacturing, bio sciences, life sciences, agri sciences

CHALLENGE THREE:

• What is the Engineering Grand Challenge?

The development of integrated, smart, low carbon urban spaces within which affordable, low/zero carbon buildings and workplaces are systemically networked to provide higher quality of life. The challenge would be to develop a blueprint for sustainable urban living in the future predicted on smart technologies, renewable energy, low carbon transportation etc. that is realisable within the context of our existing urban spaces. Thus, this is as much a retrofit for the future challenge as it is a technological innovation challenge.

• Why is it important?

Efforts to reduce greenhouse gasses are piecemeal. With predicted global population growth, the vast majority of whom will live in urban environments, the challenge is to establish socio-technical models for low carbon living which harness and integrate
technologies with community-based initiatives for low carbon living. This presents an acute need for collaborative innovation across numerous disciplines and actors.

• How is the UK Research Community positioned to tackle this Grand Challenge?

All the ingredients are there – the challenge is to understand the systemic interrelationship between them and how they might be sensitively deployed within and across existing urban environments.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Engineering, Sociology, psychology, human factors, design etc.

University of Manchester

CHALLENGE ONE:

• What is the Engineering Grand Challenge?

To provide low carbon, secure and affordable energy.

• Why is it important?

The UK is facing an energy ‘crisis’, mainly due to a lack of a coherent UK strategy to meet the challenges of low-carbon, secure and affordable energy. Without research and development in this area to meet future challenges the UK will fail to meet its carbon targets, will rely on volatile imports (mainly gas) and will have high cost energy which will be detrimental to the economy.

• How is the UK Research Community positioned to tackle this Grand Challenge?

There is significant expertise across the UK to tackle the energy challenge. This should cover:

a) Supply of energy (nuclear systems and fuel, wind, marine, solar, oil and gas, Bio, hydrogen, etc.)

b) Distribution (networks, storage, and balance of supply and demand).

c) Energy demand (efficiency, smartgrids, cities, etc.)

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

This is multi-disciplinary.

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

Advanced Materials

• Why is it important?
The use of advanced materials spans all industrial sectors. It involves the introduction of new materials (i.e. graphene, 2-D materials, new alloys etc.) the use of existing materials, and the development of advanced manufacturing processes of components, that will operate under different (harsher) environments.

The UK has a leading position on advanced materials and manufacturing which is important to underpin long-term sustainable growth in the UK economy.

• How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has significant expertise in this area but is lacking large testing facilities for advanced materials in demanding (harsh) environments.

One approach is to establish an integrated set of test facilities across the UK to help accelerate the introduction of new materials and devices into industry. Each centre would have a different focus covering key applications and centres and would link to industrial sectors. Academics from all universities would be able to apply for access.

Some examples could include:

a) Harsh environments test lab (oxidation, corrosion, high temps and pressures)
b) Irradiation test lab.
c) Civil/Structures test lab.
d) Impact/high strain rate test lab
e) Power distribution

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

This is multi-disciplinary.

CHALLENGE THREE:

• What is the Engineering Grand Challenge?

Climate change

• Why is it important?

Consequences for the plant and future generations.

• How is the UK Research Community positioned to tackle this Grand Challenge?

Fairly well although a bit fragmented across the UK. Tackling climate change should be driven by Engineers and cover all aspects from manufacturing, energy, infrastructure, transport, policy, behaviour, etc.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?
Again, multi-disciplinary

Newcastle University

CHALLENGE ONE:

• What is the Engineering Grand Challenge?

Identify and demonstrate socio-technical techniques to radically reduce resource consumption, make its distribution more equitable, eliminate associated waste and mitigate pollution effects on whole ecosystems.

• Why is it important?

At present 177 million tonnes of municipal solid waste is disposed of per annum in England alone. Although waste disposal and associated environmental impact can be seen as both economically and environmentally unfavourable; the current situation within the UK and the wider grouping of EU member states is an example of on-going positive change in response to a clear and decisive shift in policy. Specifically, the implementation of the EU Landfill Directive is often stated as a key driver for change. In response to the Landfill directive the UK government subsequently made substantial investment in waste infrastructure (£3.5 billion) through local authorities. Investment has also focused on technological advancement of waste management systems, innovative approaches to waste treatment, and social change in terms of waste perception. In combination this socio-technical approach has resulted in a startling increase in recycling and reuse of material from a baseline of 11% in 2000/2001, to approximately 43% of UK municipal solid waste in 2011-12. This compares favourably with the global situation, where ~80% waste is disposed of to landfill or incinerated (with, or without energy generation). Although the UK has significant proven capability in terms of the environmental and economic sustainability, social and technical approaches to consumption and waste from regional to international scales present significant opportunity for further gains to be realised.

• How is the UK Research Community positioned to tackle this Grand Challenge?

Particular strengths and areas of research excellence exist in characterisation of natural and anthropogenically altered ecosystems; waste management and treatment (including development of novel waste treatment systems, biological systems and biodiversity modelling); manufacturing and process engineering and intensification; and the use of digital technology to support decision making, and improve processes.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Chemical Engineering, Mechanical Engineering, Civil Engineering, Electrical Engineering, Chemistry, Biology, Social Science

CHALLENGE TWO:

• What is the Engineering Grand Challenge?
Through research, innovation and development of solutions, drive forward practical step changes in production and process efficiencies, such that the natural environment and its resources are safeguarded.

• Why is it important?

Population expansion and greater affluence (in many cases based on inequitable wealth distribution) has resulted in exponentially increasing demand for natural resources and consumer goods. Increased human populations are correlated with species extinction, which are now at rates comparable to previous global mass extinctions. This growth often leads to degradation and depletion of the natural resource base, which is in turn affected by climate phenomena and natural cycles. Increasingly complex enhanced or mechanised processes can, in some cases, enable resources to be exploited and consumed faster than they can be replenished; the global built environment consumes 3 billion tonnes of raw materials annually. Conversely, in certain industries, production standards are “preserved” through persistence with resource-inefficient methods. Considerable improvements in manufacturing and resource recovery are required to achieve a balanced and sustainable future for the production industry. Changing attitudes and behaviours will also be necessary to reduce dependence on unsustainable production methods.

In many cases, there is still significant potential and a need to expand fundamental knowledge about the functioning of whole systems, their disturbance thresholds and inherent resilience. Decision and policy making would benefit greatly from, and be more effective, when drawing on full analysis of the range of potential impacts and consequences. Achieving a sustainable outcome is more likely when goals such as profit maximisation are not considered in isolation, and legislative changes are proactive rather than responsive. Therefore, a great opportunity exists to feed into, and improve, transparency and informed decision support; resulting in significantly improved policy formulation and impact. A major area for research exists around consideration of whether resources can be adequately substituted or effectively transplanted to reduce or eliminate the impacts of alternative uses of a site. Policy makers are inclined to work in economic and equivalent measures which, while well understood, are not always straightforward to apply in complex natural situations.

• How is the UK Research Community positioned to tackle this Grand Challenge?

The use of resources for energy generation is a core area of interest, with a focus on low carbon forms of energy distribution, management and consumption, link to Integrated Infrastructure.

Improved production and manufacturing, including process intensification, substitution, efficiency and alternatives, are inherently important. Re-use, recycling (link to Consumption and Waste), and in particular the use of waste products (e.g., sewage, heat, by-products, food) as a resource provide opportunities for real step changes in the way products are manufactured and resources are consumed. There is great interest in novel methods for recovering energy, minerals, water and other vital components of manufacturing processes.

Whole system analysis, Life Cycle Assessment – there is significant potential to build upon expertise in holistic investigation and understanding of all stages of supply chains. Opportunities exist for revolutionising a variety of processes, including food and energy production.
Research that cuts across the levels of complex supply chains, looking at process intensification and with a particular focus on catalysis, offers a potential novel mechanism for real, practical advances in production efficiency. Renowned strength in chemical engineering and the chemistry of production concepts – developing more efficient methods and novel products in collaboration with industry. The provision of fully integrated and accessible decision support tools is an important part of translating and disseminating these research findings to achieve real world impact.

The areas of nanomaterials and bioprocessing – advanced understand of underlying complexity at extremely small scales – open up huge possibilities for transforming production systems. The ability to manipulate the behaviour and properties of materials or structures, in order to realise improved whole process design and sustainability, offers the potential to fundamentally improve the ways in which products are manufactured.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Chemical Engineering, Mechanical Engineering, Civil Engineering, Electrical Engineering, Chemistry, Biology, Social Science

CHALLENGE THREE:

• What is the Engineering Grand Challenge?

Transform methods used to design, implement and manage our transition towards integrated infrastructure systems such that they better serve the needs of society, and ensure positive interactions with the environment.

• Why is it important?

The national infrastructure is fundamental in strengthening and driving the economy, creating jobs, acting as a key enabler for future economic development and rising living standards. The National Infrastructure Plan 2013 (NIP 2013), from the UK Treasury, contains information on £375 billion of planned public and private sector infrastructure investment. Through NIP 2013, the UK Government has brought investment related to science and innovation into its list of Top 40 priorities alongside an integrated transport system, digital networks, sustainable, reliable and affordable energy, and water and waste.

The OECD (Organisation for Economic Co-operation and Development) estimates infrastructure investments in 2000-2030 will be approximately US$71 trillion worldwide or 3.5% of Gross World Product. The effective integration and transformation of infrastructure systems promises to contribute towards issues of enormous socio-economic importance considering the resource challenges, population increases and climatic changes faced by national and international communities.

• How is the UK Research Community positioned to tackle this Grand Challenge?

Global changes in population, demographics, technology, and climate are placing profound stresses on the infrastructure and systems that support our livelihood, wellbeing and safety as well as the intrinsic and extrinsic value of the natural environment. Our infrastructure and systems are required to evolve to reflect the changing scale and nature of the demands
placed upon them. This may require a transition towards integrated systems which encompass not only the need for physical resources but also new information and communication technologies whilst being sensitive to drivers such as the decarbonisation agenda and financial constraints. Infrastructure systems have been used to deliver economies of scale that have extended our capability to deliver improving quality of life. However, it is unlikely that continuous expansion without change can be maintained indefinitely, and there are external effects associated with infrastructure: pollution and environmental damage, increased consumption, and structural inequalities that move away from a sustainable society. The engineering, planning and operating of our urban and rural communities requires specialist consideration of their individual components (such as roads, urban drainage systems and natural resources) but also the understanding of how these relate to the larger systems in which they operate (such as transport networks, ecosystems, river catchments and neighbouring communities). Sustainable and resilient infrastructure could benefit from integrated planning and modelling of settlements, land-use, water-use, biodiversity and engineering infrastructure (including adaptability and resilience) alongside a sound regulatory framework and governance system to ensure society, industry and the environment can flourish side by side. This should be informed by an understanding of public attitudes and preferences towards the design and implementation of new infrastructure projects, particularly in cases where there are potential conflicts with other highly valued land uses. There is a drive to transform existing methods used to design and implement integrated infrastructure systems such that they better serve the needs of society today and of future generations, and to ensure positive interactions with the environment. The issues around these infrastructure systems are complex, multifaceted and interconnected underscoring integrated infrastructure as a global sustainability challenge.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Chemical Engineering, Mechanical Engineering, Civil Engineering, Electrical Engineering, Chemistry, Biology, Social Science

University of Nottingham

CHALLENGE ONE:

- What is the Engineering Grand Challenge?

Achieving Resilience and Sustainability

Resilience is the capacity of a system to survive, adapt, and grow in the face of unforeseen changes, even catastrophic incidents. Resilience is a common feature of complex systems, such as companies, cities, or ecosystems. These systems perpetually evolve through cycles of growth, accumulation, crisis, and renewal, and often self-organize into unexpected new configurations.

Sustainability is an attribute of dynamic, adaptive systems that are able to flourish and grow in the face of uncertainty and constant change. Achieving sustainability will require innovation, foresight, and effective partnerships among corporations, governments, and other groups.
• Why is it important?

There is a need to design and adapt cities and urban systems of infrastructures (i.e. water, waste, energy, transport, ICT, food, etc.) to be both sustainable and resilient.

We need to embrace change for the better, establishing how we turn disasters, shocks and stresses affecting our urban systems into opportunities to effect real improvements in the long-term sustainability of a city and the well-being of its citizens.

We must avoid being locked-in to technologies, infrastructures and systems that reduce opportunities for change, and establish what mechanisms can be identified to create change once lock-in seems to have occurred.

We must improve our understanding of the interdependencies that currently exist between urban systems and between the urban systems and regional, national and international systems. How might these interdependencies change with new technologies and new ways of doing things as we move towards more sustainable systems? What vulnerabilities do these interdependencies introduce into cities and how might we reduce them?

• How is the UK Research Community positioned to tackle this Grand Challenge?

This is a broad topic which draws upon many disciplines: engineering, science, social sciences in particular. We certainly have broad strengths to address the underlying issues, and there is alignment with the Catapults, in particular Future Cities, Transport and High Value Manufacturing. New thinking in this area would provide the pipeline necessary for the Catapults to sustain success over an extended period.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

See above.

CHALLENGE TWO:

• What is the Engineering Grand Challenge/ why is it important?

Supporting our ageing population

We considered this proposition on the basis of the evidence of the major demographic changes in the UK’s population (1): 5½ million more elderly people in 20 years’ time, 19 million by 2050; 3 million people aged over 80 now, projected to almost double by 2030 and reach eight million by 2050; while one-in-six of the UK population is currently aged 65 and over, by 2050 one in-four will be; in 2008 there were 3.2 people of working age for every person of pensionable age which will fall to 2.8 by 2033; the over 60s have outnumbered the under 18s for over five years now in the UK.

NESTA’s view is that “Innovation must match challenge of ageing population. The UK population is ageing by five hours a day but innovation is lagging behind. Society is changing. We need to rethink retirement. The traditional binary transition from work to rest is increasingly outdated. This is as much a social imperative as an economic one. 60 is the new 50. Almost half of those aged 60-64 consider themselves in “middle adulthood”, and near 1 million people over 65 are continuing to work.”
CHALLENGE THREE:

1. **What is the Engineering Grand Challenge/ why is it important?**

**Step Change Materials and Manufacturing Technologies**

Manufacturing research in the UK (and elsewhere) focuses largely on understanding of and improvements to existing processes or the business systems associated with them. There is very little research at present on new manufacturing processes. This is certainly true within the EPSRC portfolio of Centres for Innovative Manufacturing. How can we achieve a step change in the utility of manufacturing processes? As an example, how could cycle times in manufacturing of advanced composites be reduced by a factor of ten? How could unit cost and lifecycle cost of components produced be reduced by a similar level?

We would contend that this challenge can only be addressed by integrating research into materials and structures with research on advanced manufacturing. One route would be to utilise optimisation techniques based on material/structural design to determine the most desirable outcome, unconstrained by any consideration of how the material/structure combination would be produced. A suitably profitable solution would then justify significant investment in the development of entirely new manufacturing processes.

2. **How is the UK Research Community positioned to tackle this Grand Challenge?**

We have significant expertise in manufacturing process technology and in materials science and engineering in the UK, hence we are excellently placed to address this challenge. One mechanism to stimulate this area would be to focus renewal of EPSRC Centres for Innovative Manufacturing (the argument for which must surely be won) on moving down the TRL scale, with incremental work based on the first 5-years directed to TSB, HVM Catapult, Horizon 2020 or direct industry funding.

3. **From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?**

See above.
First of all the context: there is a widely (and quite strongly) held view within this Department that EPSRC is focusing too much effort on “themes”, “challenges” etcetera, with a resulting neglect of the broader swathe of fundamental science and engineering that it should be supporting through responsive mode. There is I think a very strong case for having a much more limited fraction of funds being managed through these programmes. Many seem to support work that is intellectually not as challenging nor as rigorous than the level required for responsive mode work. There seems to be too high a fraction of funds distributed under schemes which can potentially only attract a small field of entries, with (I am afraid) a suspicion of an element of cronyism within some of the programmes.

A secondary effect of the plethora of managed programmes is that it is becoming increasingly difficult to win funding for the “dull but important” work, as funds seem to go more and more to fashionable areas. “Incremental” often seems to be treated as synonymous with “sub-standard”, which is a pity – not every piece of research can be a breakthrough, and it is very important to consolidate and develop (“increments”) as well as to open up new areas.

Having said that, the broad areas which we see as providing the important challenges are:

1. Energy – with the twin drivers of climate change and security of supply, energy is overwhelmingly the largest problem of the 21st century. If we can crack this one we shall have the wealth to cope with all the other challenges, but if we do not, we shall be so impoverished that we won’t be able to do much. The challenge covers the full range from supply, storage, distribution and (efficient) end use.

2. Applications of communications and IT – although we have already seen huge progress, there are tremendous further opportunities in this area, including many that overlap with the above (e.g. smart use of IT to displace the need to energy supply).

3. Applications of technology to healthcare – again huge progress has been made, but this will be an ongoing theme for many years.

4. Transportation technologies (in the widest sense) – again relates to both 1 and 2 above.

I could go on to add many other items, but I think the above are the main themes. Most importantly though, these need to be underpinned by fundamental work in materials, computation, mathematics etc.

University of Southampton

CHALLENGE ONE:
• What is the Engineering Grand Challenge?

RESOURCE EFFICIENCY (ENERGY AND MATERIALS)
• Why is it important?
REDUCTION IN PER CAPITA AND INDEED TOTAL ENERGY USE THROUGH EFFICIENCY AND LIFESTYLE CHANGES IS ESSENTIAL IF WE ARE TO HAVE A CHANCE OF REDUCING CO2 EMISSIONS SUFFICIENTLY AND IN TIME TO AVOID CATASTROPHIC CLIMATE CHANGE. AS THE WORLD’S POPULATION INCREASES IN NUMBER AND DEVELOPS MORE AFFLUENT LIFESTYLES, RESOURCE USE PER CAPITA WILL HAVE TO REDUCE AS THERE SIMPLY WON'T BE ENOUGH TO GO ROUND AT CURRENT RATES OF CONSUMPTION.

• How is the UK Research Community positioned to tackle this Grand Challenge?

WELL PLACED, THANKS TO INITIATIVES OVER THE PAST DECADE OR MORE THAT HAVE BUILT CAPACITY IN RELEVANT AREAS. THESE INCLUDE THINGS LIKE THE LIMESNET CONSORTIUM IN CONSTRUCTION, AND JULIAN ALLWOOD’S WORK WHICH HAS SET OUT AN EXCELLENT UNDERSTANDING OF GLOBAL MATERIALS FLOWS.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

MOST BRANCHES OF ENGINEERING HAVE A ROLE TO PLAY, FROM MATERIALS SCIENCE THROUGH TO CIVIL ENGINEERING AND CONSTRUCTION (MUCH OF THE MATERIAL USED IN BUILDINGS IS NOT NEEDED!) BEHAVIOUR CHANGE WILL ALSO BE IMPORTANT, SO QUANTITATIVE SOCIAL SCIENCE HAS A ROLE AS DOES CLIMATE SCIENCE, GEOLOGY FOR NATURAL RESOURCES ETC.

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

DEVELOPMENT OF A RESILIENT INFRASTRUCTURE

• Why is it important?

WE TAKE OUR INFRASTRUCTURE FOR GRANTED, YET AS WE BUILD MORE IT BECOMES LESS AND LESS AFFORDABLE TO REPLACE. INFRASTRUCTURE NEEDS TO BE MADE ADAPTABLE TO FUTURE CHANGES IN USE AND DEMAND, AND ALSO RESILIENT AGAINST THE IMPACTS OF CLIMATE CHANGE. THE RECENT STORM DAMAGE AT DAWLISH AND EMBANKMENTS SLIPS ALL ROUND THE UK AS A RESULT OF THE VERY WET WINTER OF 2013/4 AMPLY DEMONSTRATE THIS.

• How is the UK Research Community positioned to tackle this Grand Challenge?

WELL PLACED, THROUGH BOTH GENERAL INITIATIVES SUCH AS THE INFRASTRUCTURE TRANSITIONS RESEARCH CONSORTIUM AND SPECIFIC, MORE TECHNICALLY FOCUSED INITIATIVES SUCH AS THE FLOOD RISK MANAGEMENT CONSORTIUM, TRACK 21, I-SMARTS, ETC.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

CIVIL ENGINEERING IN PARTICULAR, BUT ALL BRANCHES OF ENGINEERING WILL HAVE A ROLE TO PLAY FROM MATERIALS THROUGH TO DATA ACQUISITION AND

66
MANAGEMENT. BEHAVIOURAL CHANGE / ACCEPTANCE OF RISK SO QUANTITATIVE
SOCIAL SCIENTISTS, AND CLIMATE CHANGE SCIENTISTS WILL ALSO HAVE A ROLE
TO PLAY.

CHALLENGE THREE:

• What is the Engineering Grand Challenge?

CLEAN WATER, CLEAN AIR AND CLEAN LAND

• Why is it important?

AS THE WORLD’S POPULATION INCREASES, WATER WILL BECOME SCARCE IF NOT
PROPERLY MANAGED. CONTAMINATED LAND AND AIR POLLUTION ALREADY
REPRESENT MAJOR THREATS. WE NEED BETTER MANAGEMENT OF INDUSTRY
ACTIVITY AND BETTER CLEAN UP TECHNOLOGIES IF WE ARE TO ACCOMMODATE
FUTURE POPULATIONS IN A HEALTHY WAY. MEDICAL INTERVENTIONS ARE NICE,
BUT THE BASICS ARE CLEAN AIR, CLEAN WATER AND CLEAN LAND – WHICH WILL
SAVE FAR MORE LIVES AT A MUCH LOWER COST THAN NEW DRUGS AND
BIOTECHNOLOGICAL DEVICES.

• How is the UK Research Community positioned to tackle this Grand Challenge?

REASONABLY WELL PLACED – THE WASTE AND POLLUTION MANAGEMENT
INITIATIVE DEVELOPED SOME EXPERTISE AND THERE IS EXPERTISE IN AIR
POLLUTION EG THROUGH THE UK TURBULENCE CONSORTIUM, BUT I FEEL THE
MOMENTUM HAS BEEN LOST IN THE PAST 2-3 YEARS.

• From which research disciplines do researchers need to be drawn from to tackle this
Grand challenge?

MOST BRANCHES OF ENGINEERING – CIVIL ENGINEERING, PROCESS
ENGINEERING, GEOTECHNICS, LANDFILL ENGINEERING, PUBLIC HEALTH AND
WATER TREATMENT, FLUID DYNAMICS, CHEMISTRY AND BIOLOGY FOR POLLUTIO
AND CLEAN UP, SOCIAL SCIENCE FOR HUMAN EFFECTS AND INFLUENCES, EARTH
SCIENCE AND OCEANOGRAPHY.

University of Strathclyde

CHALLENGE ONE: Clean and sustainable energy generation and distribution

• What is the Engineering Grand Challenge?

Researchers and energy providers must collaborate to optimise the balance of energy
sources and to re-structure the use of energy to ensure environment sustainability. A
significant element of this is the generation, transmission and distribution of electrical energy
and the electrification of heat and transport. Significant advances are still required in areas
such as electric vehicles and their integration into the grid, new renewable/low carbon
energy technologies and their integration, energy storage and the link between home energy
management systems, grid operation and demand side responses. This will require the
architectures, control and distributed intelligence within new and smarter grids to be fully
defined while ensuring the approaches adopted and market mechanisms drive consumer participation. In addition, condition monitoring, asset management and asset decommissioning will continue to provide challenges in all areas of the energy infra-structure including nuclear energy and off-shore wind in particular.

- **Why is it important?**

It is important for sustaining the environment and mitigating climate change impacts. It is also important for national security in terms of minimising dependency on other nations.

- **How is the UK Research Community positioned to tackle this Grand Challenge?**

The UK research community in energy is well positioned in terms of expertise and capacity in various universities to address this challenge. Energy providers and distributors are tightly engaged with research teams and that engagement must be nurtured through consistent funding.

- **From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?**

Expertise from the following disciplines will be required: Electrical and Mechanical Engineering for developments in generation, transmission, distribution and usage; ICT expertise and sensing is critical to the underlying intelligence, monitoring, control and data management approaches required for the next generation of energy systems; new digital technologies will also drive the interactions between consumers and the energy system; Architecture and the built environment for energy efficient buildings and communities; Chemical Engineering for some aspects of energy storage (e.g. electro-chemical techniques and batteries); Civil Engineering and geo-technical engineering for the energy-related aspects of land use/development (e.g. nuclear waste storage); marine and ocean engineering for off-shore wind.

**CHALLENGE TWO: Health**

- **What is the Engineering Grand Challenge?**

There are a number of Engineering Grand Challenges that impact on health and the ability of healthcare systems to deliver effective and targeted patient management for the future benefit of society. Current health care systems are reactive to people in whom the symptoms of disease, functional loss or disability are reported or identified. The future need is to re-engineer clinical and social care toward prevention, life course monitoring, early diagnosis and precision treatment informed from evidence based interventions and support (medical, assistive & behavioural) that can be delivered at home or in the community. The engineering challenge for health care in developed economies is to fully embrace prevention and early disease detection throughout life. To achieve this, autonomous and pervasive systems that have the capacity to track an individual's health, wellbeing and capability over their life course will be needed. There are many challenges involved with the development, integration, validation and deployment of the suite of cross disciplinary technologies required from engineering (ICT and sensing), mathematics, clinical and life sciences, and social sciences
In low income countries the challenge in health is simply to deliver basic levels of health care access to those affected by poverty, disease and disability.

• Why is it important?

It is important for both the well-being of the population and the economic health of developed nations, but also for supporting the basic human rights of people affected by illness and disability in low income countries.

• How is the UK Research Community positioned to tackle this Grand Challenge?

ICT, telecommunications and sensor technologies linked to clinical and life science expertise provide the keys to delivery of this grand challenge. The UK research community is strong in these areas, but much of the effort to deliver the digital health and independent living agenda is focused on the older population and not on prevention. In low income countries the skill sets we possess need to be directed to ways in which health care can be delivered remotely and in a cost effective way. Encouragement is required to integrate expertise from across engineering, clinical, life science and social science disciplines to focus on the challenge in relation to entire populations.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

The fundamentals for this grand challenge will stem from researchers drawn from the following communities- Biomedical Engineering; Electronic and Electrical Engineering (ICT and sensing); Computing Science; Mathematics and Statistics; Public Health; Clinical Medicine; Allied Health Care; Life Sciences; Behavioural and Social Sciences; Health Economics. Built environment related disciplines will also be required to ensure the effective deployment of solutions.

CHALLENGE THREE: Environment and Sustainability

• What is the Engineering Grand Challenge?

The challenges lie in achieving the next generation of resilient cities and city systems, realising the next generation of smart and sustainable infra-structure and understanding and mitigating against environment degradation, climate change impacts and a wide range of other risks – as well as optimising the realisation of wider social and economic goals. Solutions will emerge from designing, creating and managing systems and infrastructures (energy, water, transport, communications, buildings) to have longer operating lives; ensuring resilient performance in changing contexts (such as city refurbishment); adaptability to changing societal and economic needs; improved transport management; ability to respond intelligently, safely, and efficiently to the behaviour of integrated systems; meeting societal needs more effectively; reducing the lifetime costs of infrastructure; and facilitating the reuse and recyclability of materials. In relation to future cities, the main challenge will be to create fully attributed digital representations to support a range of new information services.

• Why is it important?
With current population growth and behavioural trends (migration to cities) demand for resources will increase significantly, with serious environmental, climate, economic and political impacts. However, cities also offer a major opportunity to improve the quality of life for hundreds of millions of people across the world through focussing resources, raising standards of living, and delivering improved services (in health, education, etc). Engineering, social and economic systems need to be integrated and focussed on mitigating threats to global resources and environment, maximising the positive impacts of cities and creating solutions for a wide range of differing city contexts globally.

- How is the UK Research Community positioned to tackle this Grand Challenge?

Expertise exists in the various strands required to address the challenges, but a more joined up collaborative approach is required; the formation of cross-disciplinary teams must be encouraged.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

All areas of engineering in conjunction with architecture and planning, social sciences, policy making, risk management and economics.

Note: All of the above challenges will require the existence of simulation tools for use to appraisals the cost and performance of proposed solutions, with outcomes expressed in terms of the range of cost and performance aspects of interest to all stakeholders. The UK research community has significant collective track record in this regard.

**University of Surrey**

**Future Healthcare**

- Why is it important?

With an ageing population, advances in healthcare rely heavily not just on the biological and medical sciences but increasingly draw on engineering disciplines. This is not just for medical devices and imaging but draws on engineering skills for modelling the clinical decision making process and the demand for advanced equipment, as well as modelling processes on the molecular, cellular, tissue, organ and whole patient. In addition some of the new advances in cancer treatment, e.g. proton therapy (in which the government has just invested £250m) draw heavily on skills such as accelerator design, imaging, detection, dosimetry, medical physics. Moreover there is a lack of people with the skill sets needed in this new area which crosses the traditional research council boundaries.

- How is the UK Research Community positioned to tackle this Grand Challenge?

The UK research community is well positioned to tackle these grand challenges but it needs detailed discussion with research councils to understand that a continuum of research between research councils needs to be undertaken to optimise the impact on the economy and society. There is also an opportunity to train the next generation of researchers in this multidisciplinary field, with opportunities to work with CERN and NPL to achieve this.
• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

All Engineering disciplines, medical physics, physics, chemistry, biology, medicine, psychology, sociology…..

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

Clean renewable energy provision

• Why is it important?

Maintenance of our civilization depends on adequate supply of power but the health and success of future civilizations depends on doing this without compromising the environment. With unlimited energy available at an affordable cost, development of economies, a better standard of living, clean water provision, transportation, etc can all be addressed.

• How is the UK Research Community positioned to tackle this Grand Challenge?

This is probably the only instance where standard Keynesian economics does not hold in that supply outstrips demand … but the cost of energy keeps rising. i.e. there are over 165,000 TW per day of energy hitting the earth due to the sun, with the total world population using less than 15 TW per day equivalent. The reason for the waste in energy is not having an economically sustainable route for energy harvesting and storage.

So, the Big Issue is ‘materials development’ to capture this wasted energy. Energy conversion from the sun to a usable format, which should also include energy storage and transportation via a smart grid, must be covered in a holistic manner in a single grand challenge. This could be the development of ‘materials systems’ to demonstrate and scale up systems engineering or more suitably demonstrate and manufacture such a holistic energy system.

A start has been made in addressing these issues via the SUPERGEN initiatives and the ETI. However, there is an incremental flavour to the work being conducted. The UK needs a ‘man on the moon’ challenge to get the research community together to deliver a spectacularly successful outcome.

This is not by following industry norms to get more efficient systems, but with a paradigm change to create a disruptive technology, with high risk. It needs a major ‘Disruptive Energy Centre’, or ‘centre for the manufacture of energy technologies’, with a budget in excess of £20m …. Much like the outcome of the Quantum Technologies challenge. The outcome can be in a demonstrable desktop system that can be scalable and with industry prototypes for cheap energy, storage and usage at an affordable cost.
• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

All branches of engineering & science

CHALLENGE THREE:

• What is the Engineering Grand Challenge?

Integratable and multi-functional electronic technologies

• Why is it important?

In the emerging era of ubiquitous, embedded functionality a new type of non-conventional semiconductor cum communication innovation laboratory is required to realise next generation large area electronics that will be all pervasive and highly immersive. The human–machine interfaces will be larger, sharper and more interactive.

Microchip evolution resulted in information technology and the convergence of ICT with broadcast entertainment platforms unimaginable 40 years ago. Similarly, printed and organic electronic devices will underpin a convergence of all-encompassing functionality in engineered systems and the built environment.

The evolution of printed / organic electronics is about cost-effective provision of multiple functions within relatively large devices, from beer mats to cladding panels and aircraft. It concerns the integration of energy harvesting, storage and use; the integration of multiple sensing modalities with control and communication.

• How is the UK Research Community positioned to tackle this Grand Challenge?

Parts of this work are being addressed but the need is again for an integrated approach within the frame of a Grand Challenge. The UK community has world-leading research in related fields and is in a good position to respond.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Principally physics and electronic engineering, but drawing on research in other areas of science and engineering.

University College London

1. The complete 'in-silico' model of human physiology. Imagine being able to test new drugs, identify individual medicines and diagnose complex systemic illnesses ... all in the computer. This is not just a problem for life scientists but it is probably the biggest engineering modelling challenge imaginable. We must integrate models of structures, biochemical processing, fluids - across scales - from molecular to environmental. This is a big science challenge but it really needs engineers familiar with the complexity and size of this problem.
2. The embracing cyber-physical design methodology. Real-world systems comprise electronic, mechanical, chemical and software components. Can we come up with a design approach which allows us to develop these complex cyber-physical systems within a common framework. Can we identify design solutions that trade-off between these different classes of engineering approach. Can we analyse properties that come from composing technologies.

3. Can we make a big city like London wholly bicycle friendly? Imagine combining smart cities with sustainable transport with environmental interventions with policy and behaviour change. Imagine personal protection technologies and vehicle sensors that guarantee rider safety. Imagine lightweight battery enhancement to bicycles to make longer range urban journeys practical.

Warwick University

CHALLENGE ONE:

• What is the Engineering Grand Challenge?

The advancement of Synthetic Biology (SB) through the development of scalable, robust and biologically compatible design principles.

Synthetic Biology, the ‘true’ engineering of biological systems, aims to use design principles similar to those successfully applied in conventional engineered systems (e.g. predictive modelling, component (parts) based construction of systems, design development cycles etc) to develop novel biological systems. For this aspiration to be realised new systems orientated and biologically compatible design protocols (tools) must be developed.

• Why is it important?

The importance of SB has been articulated in a variety of publications (including reports commissioned by BIS and the RAEng). The potential commercial impact of SB is far reaching and covers many industrial sectors. SB also possess the potential to advance fundamental understanding of biological function thus leading, for example, to the improved treatment of a wide range of pathologies as well as new synthetically derived pharmacological interventions.

• How is the UK Research Community positioned to tackle this Grand Challenge?

There are a number of world leading SB groups currently established in the UK but very few are embracing the challenge of developing new systems orientated and biologically compatible design protocols (tools). Without these ‘tools’ SB will have limited scope. For example, the number of ‘biological parts’ currently realised in SB systems is small; in other words current SB approaches are non-scalable. Without the development of new design tools there is little chance of developing scalable engineered biological systems.

The group at Imperial are currently addressing these issues through the ‘orthogonal parts’ and minimal cell approach; indeed this has become the standard SB methodology pursued internationally. But this approach must be augmented with biological compatible design rules that take into account for the stochastic, complex, adaptable nature of biological systems. This will require an integrated science and engineering approach that includes physicists,
mathematicians (in particular complexity scientists), systems engineers and biologists, computer scientists, chemists and life scientists.

The UK is well placed to lead in the development of the appropriate design methodologies. Through EPSRC and BBSRC funding capacity at the UK level has already been developed in a number of key areas, namely: complexity science, systems engineering and systems biology. This capability, coupled with our strength in the life and physical sciences, positions the UK ideally to take on this challenge.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

See above.

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

There is a national need to invest in resilient infrastructure (e.g. see National Infrastructure plan 2013)

For resilient infrastructures there is a need to understand, model and predict the long-term (durability) performance of construction materials and their structural systems.

• Why is it important?

To reduce failures and the cost of inspection and maintenance of the UK infrastructure so that it remains, over the required working life, fit for society’s needs; thus significantly reducing ongoing maintenance and replacement costs.

• How is the UK Research Community positioned to tackle this Grand Challenge?

To facilitate material scientists, production and structural engineers in interdisciplinary research to develop, process, characterize with construction materials (such as composites) to enable safe (structural engineering) design for infrastructural projects subjected to varying environmental and live loads for 50 to 100 years.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Manufacturing, material scientists (chemistry), structural engineering (aerospace and civil).

CHALLENGE THREE:

• What is the Engineering Grand Challenge?

PREDICTIVE MODELLING: The challenge is to move computer modelling into the true engineering environment where uncertainty and tolerance must be built in as essential, often safety-critical, features.

• Why is it important?
Clearly has immense intellectual challenges, with the practical consequences of pushing forward a whole range of computer simulation techniques and creating a potentially disruptive enabling technology for all the UK and EU priority areas. Benefits to industry should be significant and include the rapid development and uptake of novel advanced materials and reduced testing and commissioning costs; these benefits will be realised over a wide range of industrial sectors.

• How is the UK Research Community positioned to tackle this Grand Challenge?

We are now seeing the first (tentative) steps towards integrating the best of current modelling theory and technique with sophisticated statistical methods and deeper reference to underlying physical principles to produce cross-disciplinary, multi-scale and consistent approaches to predicting behaviour in fields such as materials engineering, optimal mechanical design, flow systems (fluids, heat, etc.), electronic devices with lattice defects, biomedical models and many more. This is a rapidly moving field led by the US, however the UK has strengths in all the necessary disciplines to make a significant international impact.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

See above.

CHALLENGE FOUR:

• What is the Engineering Grand Challenge?

Surface Engineering & Thin Systems.

Comprising engineering-centred fundamental research activities that draw heavily on still developing physics, chemistry and biochemistry principles, there is urgent need to gain deep understanding of, and good modelling tools for, how surfaces actually interact to influence, and often totally govern the practical performance of the majority of technological systems; surprising little is currently available to aid designers.

Furthermore, there is currently and generally very poor understanding of how measured geometry relates to function even if materials are assumed to be ideal. Certainly, little is known reliably that can translate plausible industrial measurement methods (and their summary parameterizations) into useful predictors of product performance. To draw an illustration from just one area, potentially huge improvements in energy usage, useful lifetime and safety could arise from good multi-scale techniques to relate the design of a surface (geometry and materials) to its detailed tribology. Note that even the best non-linear Finite Element package scan still do no better than handle contact, friction and wear by means of largely empirical algorithms that place great import on the experience of the analyst.

• Why is it important?

Improved and efficient methods to describe, design and manufacture functional surface regions would result in large positive, potentially disruptive, benefits to all the (technologically addressable) current high-priority needs of society: energy use; low environmental impact and sustainable manufacture; health technology; intelligent building and the modern city; underlying technology for communications and security; etc. To achieve these benefits, we
need new, better basic science, functionally oriented high-precision models, better metrological tools, new ways to control manufacture surfaces at the right level and so on, all with the aim of getting novel ways to design and control the processing of reliable, high-performance surface regions.

- How is the UK Research Community positioned to tackle this Grand Challenge?

The UK currently has good, internationally recognized strengths (academic and industrial) in most of the underpinning disciplines needed to set up this vision and so is well placed to deliver handsomely on an investment that brings more impetus and coordination to the field.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

See above

**BAE Systems**

**CHALLENGE ONE:**

- What is the Engineering Grand Challenge?
  - Integrated (Autonomous) Underwater Systems
  - High Endurance (Speed, Distance, Time)
  - Communications
  - Sensors and GPS Denied Navigation
  - Self-Reliance
  - Mission Capable Autonomy
  - Collaborative Operation between Autonomous Assets

- Why is it important?
  - Current Manned Underwater Assets are Expensive
  - Future Systems need to be Capable, Flexible, Adaptable & easily Reproducible at modest expense.

- How is the UK Research Community positioned to tackle this Grand Challenge?

All the elements are there.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?
  - Energy and Power
  - Autonomy, Automation, AI and Robotics
  - Quantum Sensor Technologies
  - Underwater Communications
  - Smart Materials (Morphing, Camouflage, Hydrophobic, Embedded Sensors)

**Dyson**

**CHALLENGE ONE:**
• What is the Engineering Grand Challenge?

Vision enabled Robotics for unstructured environments

• Why is it important?

Autonomous products have the ability to revolutionise industries and dramatically improve our quality of life but very little in the way of successful products have been developed. Key to creating robots which work well in an unstructured environment, a goal that has been elusive for decades, is having the situational perception to intelligently carry out any kind of task. Unlike many single-purpose sensors, vision sensors can enable many functions e.g. global and local environmental understanding, object recognition, visually-driven manipulation and human interaction. Effective vision-based solutions will require highly optimised algorithms that not only deliver the correct results but are able to perform effectively in real-time on low power processors.

• How is the UK Research Community positioned to tackle this Grand Challenge?

This is an area which has not been well-addressed by the wider academic community who have tended to produce algorithms requiring ever increasing computational power. The UK has strong expertise in this area, especially in the fundamental research driving the necessary algorithms. Focussing efforts on the commercial realities of delivering such systems creates new academic challenges which the UK are well placed to address.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?
  • Computer science
  • Machine learning
  • Sensors and electronics
  • Mechatronics

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

High power density, portable energy storage

• Why is it important?

Billions of pounds worth of investment are flooding into battery research. The focus in the past has predominantly been on maximising energy density driven by market requirements coming from mobile phones, laptops and other mobile electrical devices. An under researched area is that of high power density, portable energy storage. Delivering the energy to speed required for high power applications in a portable form factor would unlock a new market of products.

• How is the UK Research Community positioned to tackle this Grand Challenge?

The UK have a number of leading experts in this field.
From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

- Electrochemical
- Chemistry
- Materials Science
- Power electronics

CHALLENGE THREE:

What is the Engineering Grand Challenge?

Surface Engineering

Why is it important?

Many challenges faced by industry involve surface interactions to some extent, regardless of whether it is reducing friction from surfaces, making bearings that work at high speed or creating antimicrobial surfaces.

How is the UK Research Community positioned to tackle this Grand Challenge?

There is a wealth of experience looking at various aspects of surface interactions but there does not appear to be a cohesive strategy.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

- Chemistry
- Physics
- Biology
- Materials Science
- Tribology
- Mechanical Engineering
- Fluid Mechanics
- Aerospace Engineering
- Aeronautical Engineering
- Sensors
- Image Processing
EON

• What is the Engineering Grand Challenge?

To develop a robust and reliable electricity network for the UK, which has the capacity and flexibility to meet the demands of future energy systems.

• Why is it important?

The future of generation could take many routes; one of them is the push towards distributed generation, which when connected could have the potential to create virtual power plants and transform the energy market.

To enable future energy technologies to be utilised fully, while maintaining the required network standards for safety and operational control.

Managing the whole energy system will be more complex in most scenarios, with less centralised generation, more distributed and intermittent generation necessitating bi-directional flows and the ability to respond to demand and supply options to balance the grid.

JLR

CHALLENGE ONE:

• What is the Engineering Grand Challenge?

Low Cost Energy Dense Storage

• Why is it important?

o The need for global decarbonisation and the quest for sustainable future energy sources are well understood, however the means to achieve these goals are not. Renewable energy will play an important part in providing cheap, clean energy; but the ability to store and transport energy require further fundamental research. Affordable solutions that offer the energy density requirements for mobile use, or the storage volume for grid application are just two of many potential examples of application.

o The UK has the potential to bring a credible focus to the Battery Integration challenge from an engineering viewpoint and to reduce the complexity of the systems being used through innovative design – a UK world strength. This is a more appropriate focus and opportunity given our modest resources than cell production in which the UK is unlikely to become a major producer, although at a fundamental chemistry research level the UK still has a role to play, reflected in the commitment to by the cell scale-up facility at Warwick. We do however need to understand the potential UK role in ownership of IP and licensing in taking this to full-scale production.

o Jaguar Land Rover and UK Motorsport have a common interest in the journey toward electrification on which we are dependent on nurturing the next generation of engineers and scientists in this energy storage domain.

• How is the UK Research Community positioned to tackle this Grand Challenge?
UK universities offer a degree of world class knowledge and capability in this area in existing pockets of expertise, however, the global market for high value research in this domain is dominated by large, highly funded entities that operate at a scale not seen in the UK – e.g. Panasonic and LG Chem.

To rebuild and retain competitiveness, the UK needs a significant increase in capability in the energy storage research work-streams.

The UK has elements of all of the required disciplines for battery research:

- Fundamental electrochemistry – St Andrews, Oxford, Bath
- Modelling and application – Imperial, Warwick, Southampton
- Control – Oxford, Cranfield
- Cell manufacture - Warwick

Working together they constitute the essential building blocks for electrochemical energy storage.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

There are currently many groups receiving funding into Energy Storage into the UK, which form an established framework for the expertise. Funding to these groups should be allocated according to potential Impact. A focus also needs to be applied to new, “blue-sky” technologies for energy storage.

The key disciplines include:

Electro-Chemistry (Battery Cell Focussed); Functional Safety (York) ; Control Engineering; Electro-Chemical/Mechanical Simulation , Computing/Mathematics, Materials

CHALLENGE TWO:

- What is the Engineering Grand Challenge?

Smart and Connected

Requires the necessary scientific engineering research to achieve the operation of fully autonomous cars within a personally-oriented, information-rich environment. There are an array of specific technical challenges that need to be addressed in order to make the operation of fully autonomous vehicles within such an environment a reality but, at the highest level, the Engineering Grand Challenge boils down to four items:

- Electronic & software architecture – With such a large number of distributed electronic components interacting as part of a large-scale, complex system, what are the necessary underpinning electronic control, network and software architectures that allow co-operative, distributed, decentralised electronic decision making and control to be practical, scalable, reliable and safe?
Data fusion and analytics – How can autonomous, real-time decision making based upon massive, integrated, and sometimes conflicting data sets be realised, and how can such data processing requirements be effectively distributed across the infrastructure such that the constrained operating environment of the vehicle itself doesn’t become overly restrictive?

Validation – How can incredibly complex and unpredictable vehicle operating environments (internal and external) be accurately, reliably and repeatedly modelled and simulated such that the entire electronic and human operating and decision making network can be validated for effectiveness, efficiency and, above all, safety?

Transitioning control between vehicle and driver – How can control be safely and seamlessly passed between vehicle and driver, to enable the appropriate level of autonomous control to be taken to match the environment in which the vehicle is operation, from total manual control at one end of the scale to fully autonomous control at the other end.

All this needs to be achieved at a cost structure appropriate for the automotive industry.

Why is it important?

There are a number of significant social and environmental drivers leading to the need to develop autonomous vehicle technologies and, perhaps ultimately, fully autonomous vehicles. These include:

Improving safety and reducing accidents, injuries & fatalities – Over the past four decades there has been a gradual and significant reduction in the number of fatal and serious injuries caused by road traffic accidents in the UK mainly through the improvement of vehicle passive safety. However, the fact that a large proportion of all accidents are caused by human error, creates significant motivation towards provision of a smart/active and autonomous capability for an even greater reduction of injuries and fatalities, through active safety.

Improving efficiency and reducing carbon emissions - the potential for autonomous vehicle systems to monitor and manage energy consumption to optimal effect. Using smart infrastructure to anticipate energy consumption, comparing then with other available options for transport through the entirety of a potential multi-modal journey, improving journey efficiency and reducing congestion, also major drivers.

Improving traffic flow in the face of increased traffic density – the use of autonomous technologies to support processes such as vehicle ‘platooning’ and the creation of managed traffic zones will mean that traffic flow can be maintained and improved.

At the same time, there are significant opportunities to improve the personal experience of car owners and operators:

Seamless journey management – the ability to integrate the personal transport element of a start-to-finish multi-modal journey such that it provides its unique contribution to the experience could add significant value to the user experience.
Improved productivity and capability – making the car a seamless extension of the personal digital life of the user, enabling them to remain productive and effective whilst on the move under the vehicle’s autonomous control will be of particular benefit to business users.

Increased (but safe) enjoyment - the augmentation of manual driving control with autonomous active safety features will also help to provide a more pleasurable/less stressful and safe driving experience. At the same time, the smart, connected environment will also enable both the driver’s and passengers’ journey to be safely supplemented with personalised, journey relevant information, further enhancing their travel experience.

How is the UK Research Community positioned to tackle this Grand Challenge?

Our preliminary investigations have shown that the UK is well placed to tackle this Grand Challenge. The expertise and research focus doesn’t lie in a single institution, but our studies have suggested that there are pockets of leading scientific research across the UK in all of the disciplines, necessary to carry out a coordinated, large-scale programme of collaborative industry-university research. We are exploring the possibility of a second strategic partnership between JLR and EPRSC in this area.

From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

There is a wide variety of disciplines from which researchers need to be drawn in order to tackle this grand challenge. These include:

Data analytics & Big Data; Mathematical analysis; Computer modelling & simulation; Robotics and autonomous systems engineering; Systems engineering and integration; Artificial intelligence; Terrestrial and satellite communications; Control engineering; Sensors and instrumentation; Complexity science; Software architecture & engineering; Electronic architecture; ICT networks and distributed systems; Display technology; Energy management and efficiency; Psychology and human-computer interaction; Transport system operations & management; Law

NDEvR

CHALLENGE ONE: Engineering Infrastructure

What is the Engineering Grand Challenge?

The Challenge is to ensure the secure and safe provision of critical, societal-scale engineering infrastructure upon which a modern industrial society depends for a strong economic future.

This includes all aspects of energy systems (nuclear, fossil & renewable generation, oil & gas, and including energy transmission & distribution), water storage & distribution, transport infrastructure (rail, road, marine, air).

Why is it important?

Our engineering infrastructure represents a huge investment made over many decades. Across all infrastructure sectors, there are programmes of infrastructure maintenance, repair,
life extension and replacement, and each represents very large ongoing investments by society. Similar investments have been, and are being, made in every modern industrialised society representing a large and growing global market opportunity.

There is a significant challenge to optimise the economic value of current and future infrastructure. This will demand better informed operation and use of plants and structures provided by the smarter application of knowledge across the engineering sciences, including on-line monitoring of entire systems, interrogating performance and residual safe, economic lives at the levels of systems, components and materials. The demands on the capabilities of the engineering sciences are considerable, as are potential benefits to society. An increasingly important engineering science is the field of non-destructive evaluation (NDE) and structural health monitoring (SHM) – i.e. the ability to locate, quantify and evaluate the aspects of a structure, component or material affecting its integrity and longevity. More than ever, this has become an essential requirement for the safe and economic management of engineering infrastructure. The necessary advances required in the capability of NDE and SHM will both rely on advances in many of the physical and engineering sciences, and the enabling advances in other engineering sciences to realise the benefit for our current and future engineering infrastructure.

• How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has a strong position in many fields of engineering and physical sciences that together will impact significantly on this challenge. The UK's research community in the non-destructive evaluation (NDE) and structural health monitoring (SHM) is particularly strong, and will be a key enabler in preserving our current infrastructure and for building new where it is necessary.

Inter-disciplinary collaboration will often be essential to ensure the full capabilities of each advance in engineering science can be identified and exploited. An example would be the interconnections required for research into NDE, material science and structural integrity for the measurement of internal stress and the onset of damage/degradation (e.g. fatigue, corrosion, etc.), and the use of this knowledge for optimising the life of components.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Mechanical engineering, civil engineering, material science, non-destructive testing, physics, electronic & electrical engineering.

CHALLENGE TWO: Future Manufacturing

• What is the Engineering Grand Challenge?

There is a strong imperative to produce long-lasting, reliable, efficient, safe machinery, systems and plant using the minimum of resources throughout the entire engineering life cycles. Advanced manufacturing in fields such as aerospace, power generation and oil & gas exploitation is expected to contribute significant growth to the UK economy and provides major engineering challenges through the use of new materials, new engineering designs and extreme operating environments. This will require considerable advances in many areas of science and engineering.
An example is the goal of Damage Tolerant Design. This requires linking duty cycle (i.e. the required and intended operational performance), material properties and non-destructive evaluation (NDE) and structural health monitoring (SHM) capabilities with the economic service life, repair, refurbishment and end-of-life re-manufacturing. By achieving this goal, the economic value will be maximised.

Another important aspect of Future Manufacturing will be the concept of ‘design for NDE’ whereby the facility to apply NDE technologies is incorporated in component and product design. This is the recognition of the role NDE can play throughout the product life-cycle to maximise useful life, and that we should not continue to rely on the sub-optimal approach of using of NDE as an afterthought.

Both these goals are closely linked to the ambition of realising self-monitored and self-healing structures.

- Why is it important?

The opportunity is to incorporate all fields of engineering and technology relating to the economic life-cycle of products, systems, components and infrastructure. This will be key to selecting profitable business models and protecting long-term manufacturing competitiveness. High value components will be especially suitable for this approach which will provide a strong competitive edge in the world market.

- How is the UK Research Community positioned to tackle this Grand Challenge?

The UK has a strong position in many fields of engineering and physical sciences that together will impact significantly on this challenge. The UK’s research community in non-destructive evaluation (NDE) and structural health monitoring (SHM) is particularly strong, and will be a key enabler when working closely with researchers in the fields of structural integrity, materials, manufacturing technologies, design, etc. An example would be the interconnections required for research into NDE, material science and structural integrity for the measurement of internal stress and the onset of fatigue, and the use of this knowledge for optimising the life of components.

- From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Mechanical engineering, material science, non-destructive testing physics, electronic & electrical engineering.

**Siemens**

**CHALLENGE ONE:**

- What is the Engineering Grand Challenge?

Affordable near-zero carbon energy and its distribution/storage infrastructure.

- Why is it important?

Mankind's approach to energy has historically been reactive, and essentially based on opening up new reserves of combustible fuels with a capacity commensurate with economic
needs. The modern understanding of climate change renders this unsustainable. While there are long-term prospects (especially via fusion) of an eventual panacea, the next 50 years will need interim solutions. Renewable sources require energy storage developments to make them capable of fulfilling a sufficient proportion of the need. Affordability of very large capital projects is a limiting factor, making scalability of solutions a further research priority.

• How is the UK Research Community positioned to tackle this Grand Challenge?

Generally fairly well, with some fields (notably nuclear) rapidly regaining ground – and incidentally demonstrating the responsiveness of the general research base. Energy is a well-invested sector of the UK economy with key global players and purposeful research direction. Renewables research in wind and marine power is a natural priority for the UK, as a region of the world especially well-suited to its exploitation.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Predominantly: physics, mechanical engineering, electrical engineering, civil engineering, materials science.

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

Autonomous, low-embedded-energy transport systems

• Why is it important?

Flexible and efficient personal transport is desirably a universal opportunity, but it is also an economic imperative for the foreseeable future. This makes clean and cheap vehicles an imperative, but so also is an infrastructure that permits very large traffic volumes (compared even to today’s major city levels) to flow freely with minimised disruption. Technical advances in aviation make aircraft resistant to all forms of failure except systems failure. Making surface transport similarly resilient and “hands-free” is a challenge of scalability and volume-based cost efficiency. The fuel efficiency of road vehicles is constrained by the vehicle weight necessitated by crash resistance. There would be both sufficient existent road capacity and margins for great increases in journey speed if cars were configured to move in road-trains between population centres and as low-speed AGVs within them.

• How is the UK Research Community positioned to tackle this Grand Challenge?

Currently a low emphasis. Industrial research engagement is growing with the recovery of a UK automotive sector in particular, but addressing personal transport in systems terms is not a priority of the emergent organisations. Research may need to be government driven. Because of high population density and societal development, the UK as a country would be a principal beneficiary of research.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Predominantly: physics, electronic engineering, IT, materials science, mechanical engineering.
CHALLENGE THREE:

• What is the Engineering Grand Challenge?

Materials efficiency including especially establishment of a circular economy (maximised re-use of manufactured goods and materials, plus recovery and re-cycling of critical materials)

• Why is it important?

The sustainable use of resources tends to be characterised in terms of energy and/or water, but the greatest R+D deficit and the most extreme wastefulness are both arguably in materials use. The embedded energy content of manufactured goods is unnecessarily high, in terms of raw materials yield, inefficient design and premature replacement as well as in terms of manufacturing process consumption. Vital future technologies (for example batteries and magnets) are dependent on scarce materials with geo-political supply risks and inadequate recovery and re-cycling methods. Redress requires a full life-cycle approach.

• How is the UK Research Community positioned to tackle this Grand Challenge?

A recent focus which is now well provided for, meaning that the future challenges will be in direction and developing co-operation. Of the six Challenges cited, this is the one in which the research need runs most directly counter to vested commercial interests, and so may again need government guidance. Modelling and the simulation of large systems is a particular need.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

• Predominantly: physics, chemistry, mathematics, materials science

CHALLENGE FOUR:

• What is the Engineering Grand Challenge?

Sustainable resources for life – principally water, and (dependent on it) food

• Why is it important?

Tata Steel

CHALLENGE ONE:

• What is the Engineering Grand Challenge?

The development of intelligent manufacturing (Smart factory of the future) for mature manufacturing industry such as the steel industry via Cyber Physical System (CPS) integrating advanced process monitoring, control and optimisation inc. wireless sensor, human- machine interaction, embedded sensors and NDT technology, machine learning, simulation, soft sensing allowing more intelligent and flexible production systems with capability for self-learning and adaption. New feedback/feed forward loops will need to be developed inc. new flexible CPS architectures. Below are some of the major drivers/lines of activities to be investigated
- adjustment of control/manufacturing process parameters for meeting quality and bulk/surface state properties inc. in service performance

- real time optimisation inc. cost

- predictive capabilities of process equipment to meet current and future products inc. capability to identify critical process steps, process interactions, sensitivity and where gaps in process conditions cannot be met (identifying therefore critical process improvement, CAPEX, role of additive manufacturing, etc.)

- feedback to process design inc. constraints

- feedback to product design

- intelligent preventive maintenance (PDM) via real time condition monitoring and self learning

- knowledge extraction (context based), encapsulation and re-use

- energy stream mapping and re-use

- intelligent plant reconfiguration

- real time quality assessment of product inc. feedback from in-service performance

- new wireless sensor (type SHM structural health monitoring) via cloud architecture inc. big data and human interaction.

- potential for centralised and decentralised information accessible via portable wireless equipment (e.g. tablet or any future devices) for process capability inc. health based on proximity detection

- knowledge based system with self-learning for improvement/process modification

- move towards in-situ control and repair.

- holistic and virtual manufacturing

This will have to be supported with an off-line strategy for global/local property predictions and ways to improve interaction and use of off-line and in-line models.

• Why is it important?

- Ability to adapt quickly and in a control manner to changes in market demands at a profit.

- Ability to integrate conventional bulk technology with additive manufacturing/advanced technology to provide a step change in profitability

- zero failure

- yield and productivity improvement

- continuous improvement of knowhow with adaption
- H&S and environment
- integrated horizontal and vertical manufacturing chain
- transferable strategy to other sectors

• How is the UK Research Community positioned to tackle this Grand Challenge?

Currently for large scale bulk conventional processing, it is difficult to address the challenges stated above. This requires new direction and thinking, new specific and collaborative calls and network together with education system steered towards this ultimate challenge.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Multi-disciplinary approach from Mech Eng, physics, material science to process control/system and IT specialists

CHALLENGE TWO:

• What is the Engineering Grand Challenge?

Materials development and selection for a low carbon economy. As new energy generation and usage technologies mature, there needs to be a ‘cradle to cradle to cradle…’ approach in the design and use of materials to support this. This involves zero waste and maximum reuse of the materials whilst concurrently delivering through life performance on the application. Examples of this are non-corroding steel structures and vehicles, which are both 100% recyclable and lose no through life performance.

In addition there needs to be:

1) 100% reuse/recapture of thermal waste energy in large manufacturing, much of which is low grade heat.

2) Changing ‘waste’ into ‘products’ e.g. development of CO2 usage, steel slags.

• Why is it important?

The materials can then enter a multiple lives within a variety of products with no new resources required from the planet.

Energy self-sufficiency is a major challenge for many countries, UK included. The challenge for engineers is to provide both more cost-effective solutions and environmental credentials to provide the politicians with a publicly credible proposition.

• How is the UK Research Community positioned to tackle this Grand Challenge?

Several areas are currently being successfully developed e.g. reduced tail pipe emissions using lower density products, solar farms etc. The next step is to understand the whole system, building on the current work on Life Cycle Analysis.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?
CHALLENGE THREE:

• What is the Engineering Grand Challenge?

Cost effective materials in Extreme Environments. As society goes further to gain access to the needs of the planet, there is an increasing demand to work in more extreme environments.

For example,

• Oil and gas is consistently being obtained and transported from deeper under the sea and/or closer to polar environments. This involves both higher pressure and/or lower temperatures.

• If the potential for using the earth’s natural Geothermal heat is to be maximised, higher temperature, higher pressure and highly corrosive environments can all be expected.

• Energy storage for renewable energies e.g. wind/wave/solar needs a cost effective solution on a large scale capable of operating in a variety of environments.

New materials are available for this, however these tend to be less abundant naturally and/or prohibitively expensive. The challenge is to develop cost effective, environmentally friendly materials that are capable of meeting tomorrow's requirements. A topical example would be changing carbon (in the form of graphene) into high insulating, highly conductive coating at a low cost of manufacture.

There is also a need for all the supporting materials e.g. ultra-high tensile wires for infrastructure

Will the ultimate environment be in space?

• Why is it important?

Very expensive materials can prevent implementation of their potential benefit i.e. jumping the so called ‘valley of death’. An understanding of these barriers could accelerate deployment on a large scale.

• How is the UK Research Community positioned to tackle this Grand Challenge?

UK government policy has, for the past few years, tried to reduce the barriers on TRL levels 4 to 6 and universities have responded to this. This is an extrapolation of that policy.

• From which research disciplines do researchers need to be drawn from to tackle this Grand challenge?

Materials, Chemistry, Physics, Engineering (various)
8.4 Annex 4 - Other inputs considered by the participants

These included:

- NAE Challenges
- Horizon 2020: EU funding
- Challenge Prixes
- EPSRC Chemistry Grand challenges
- EPSRC Physics Grand challenges
- EPSRC Healthcare Technologies Grand Challenges

NAE Challenges

The NAE in the USA has released a list of the Engineering Grand Challenges as determined by committee of the National Academy of Engineering. These are:

- Make solar energy economical – enabling solar power to be a long term sustainable energy source through improving economic competitiveness. This could include improving cell design, efficiency, developing new materials, developing nanotechnology based approaches, and improving energy storage options.
- Provide energy from fusion – challenges around improving the development of advanced reactors and relevant materials, fusion generating facilities, and robotic approaches to the support of such facilities.
- Develop carbon sequestration methods – development in methods to capture and store CO2, and to alter the initial combustion process.
- Manage the nitrogen cycle – remediating disruption to the Nitrogen cycle in order to maintain a sustainable food supply for the future. This includes de-nitrification strategies, controlling the release of nitrous oxides, improving fertilizer manufacturing and the recycling of food wastes.
- Provide access to clean water – by the development of technologies including desalination, recycling of wastewater and sewage treatment, strategies for reducing water use, localisation of water treatment facilities.
- Restore and improve urban infrastructure – dealing with aging infrastructure worldwide, maintaining infrastructure for the future, building better infrastructure using new construction materials and methods, and improving transportation systems.
- Advance health informatics – improving healthcare through development of health record systems, remote sensing and monitoring devices, novel methods to prepare for pandemics, public health emergencies, and the use of chemical and biological weapons.
• Engineer better medicines – personalisation of medicine using newly available genetic information and improved diagnostics, improved drug delivery through use of encapsulation and nanoparticles, infection resistance through development of new antibiotics.

• Reverse-engineer the brain – understanding brain activity and signalling pathways, which may possibly lead to bio-inspired electronics and signalling.

• Prevent nuclear terror – reactor monitoring, transport and detection of nuclear materials, emergency response and clean-up methodologies

• Secure cyberspace – understanding and mitigating against cyber-crime and issues with cyber-security by engineering more secure software, providing better security for data flow through the internet, developing methods of detection, monitoring, and recovery.

• Enhance virtual reality – developing highly realistic virtual environments and virtual people by developing video technology, and by exploring the reproduction of sensations including touch through the integration of systems with tactile feedback.

• Advance personalized learning – neuroscience research into the neural processes underlying learning, using new medical technology to understand the brain, in order to enable software methods to optimise learning.

• Engineer the tools of scientific discovery – partnerships between engineers and other scientists to design the tools, instruments and systems which will make it possible to acquire new knowledge about the physical and biological worlds.

More information about these challenges can be found here: http://www.engineeringchallenges.org/cms/challenges.aspx

EU Funding: Horizon 2020

Horizon 2020 is the EU's main funding programme for research and innovation, and will run from 2014 to 2020. Horizon 2020 is a funding programme for all types of actors involved in research and innovation; academia, research, industry and other stakeholder organisations. Horizon 2020 is based on three pillars, as shown in the diagram below:

Within each pillar are different funding schemes, and within those a number of areas or challenges have been identified to date. Below is a summary of the currently identified areas within each theme, which are most relevant to academic researchers. A large number of these areas include a role for engineering researchers.

Pillar 1 - Excellent Science: Future and Emerging Technologies (FET)

A funding mechanism for collaborative ‘high risk’ research under three strands: FET Open, FET Proactive and FET Flagships. Within FET Proactive the themes identified for the 2014-15 Work Programme include:

• Global Systems Science (GSS)

• Knowing, doing being: cognition beyond problem solving
• Quantum Simulation
• Towards exascale high-performance computing (HPC)

Pillar 2 - Funding Innovation:

Key Enabling Technology (KETs)
• Micro- and nano-electronics
• Photonics
• Nanotechnologies
• Advanced materials
• Biotechnology
• Advanced manufacturing and processing

Public Private Partnerships:
• Factories for the Future
• Energy Efficient Buildings
• Sustainable Process Industries
• Advanced 5G Network Infrastructures
• Robotics
• Photonics

A note of caution is that the challenges in the Industrial Leadership and Key Enabling Technologies themes and calls are likely to be more implementation challenges for developer and companies than for researchers. The detail will be in the calls.

Pillar 3 – Tackling Societal Challenges

Seven societal challenges have been identified under pillar three:

1. Health, demographic change and wellbeing - The first Work Programme for this Challenge is designed around the ‘personalising health and care’ focus area, and provides opportunities for breakthrough research, including behavioural and cognitive data for early risk reduction, the virtual human, and in silico medicine

3. Secure, clean and efficient energy - The Work Programme for 2014-2015 groups the call topics into three ‘Focus Areas’ - Energy Efficiency, Competitive Low-Carbon Energy and Smart Cities and Communities

4. Smart, green and integrated transport – There are four ‘Focus Areas’ in the 2014-15 Work Programme: Green Vehicles, Mobility for Growth, Smart Cities and Communities, and ‘The Cleanest Engine’.


6. Inclusive, innovative and reflective societies – The work within this theme primarily explores economic and social research into different aspects of European societies.

7. Secure societies - Protecting Freedom and Security of Europe – This challenge aims to “develop and apply innovative technologies, solutions, foresight tools and knowledge, stimulate co-operation between providers and uses, find civil security solutions, improve the competitiveness of European security, industry and services, including ICT and prevent and combat the abuse of privacy and breaches of human rights on the internet and elsewhere, while ensuring European citizens’ individual rights and freedoms”.

More information on funding calls and mechanisms can be found on the Horizon2020 website: http://www.ukro.ac.uk/subscriber/funding/Pages/index.aspx

Each pillar can be navigated using the links on the left hand side of the page. Please note that only subscribers (the majority of UK universities) can navigate these pages, and a log-in is required. For those who are not subscribers, factsheets on each area will be available at the event.

**Challenge Prizes: Setting the goal**

Setting grand challenges is nothing new; for centuries engineers have strived to make things work better and answer the societal and technical challenges that have come along the way. It has become necessary in recent times to work in multidisciplinary teams to address the challenges that are affecting our changing world – from climate change to ever evolving technology or medical advancements – scientists and engineers are at the forefront of discovery.

Back in the 18th century the Government arranged a series of prizes under the longitude board banner; the aim of which was to determine the longitude of ships at sea in a time of increased maritime trading and warfare. Since then prizes have been seen as an effective way of galvanising researchers to address the societal issues that have arisen. In the last 10 years X-prizes have been set that offer millionaire prizes for challenges such as ultra-efficient engines or high speed genome sequencing.

Closer to home; organisations such as Nesta have set up a Challenge Prizes Centre to encourage the multidisciplinary work necessary to address them. The nature of these prizes consists on giving a small set of funds to a series of teams to develop an idea around
challenges ranging from increased energy demand to an ageing population. These teams are given time to develop their proposal and judged at the end to decide the winner. Looking forward projects around Horizon 2020 challenges of health, transport, bioeconomy, creative material and energy will be targeted.

**EPSRC Chemistry Grand Challenges**

The Dial-a-Molecule (http://www.dial-a-molecule.org/wp/) and Directed Assembly of Extended Systems with Targeted Properties (http://beyondthemolecule.org.uk/d6/ - usually known as “Directed Assembly”) Grand Challenge Networks were originally set-up in 2009 by the EPSRC Physical Sciences Theme with 18 months of pump-priming Network funding, to identify and begin to develop, broadly speaking, the potential for transformative change in Organic Synthesis (Dial-a-Molecule) and Materials Assembly across the length scales (Directed Assembly).

Overall, both Networks have delivered impressively on their initial aims, and both have received continuation funding (for the approximate period 2012-2016) at an enhanced level, to continue and expand Networking and introducing modest pump-priming activities. Necessarily, both have demonstrated appropriate engagement with their communities and evident expansion of Network engagement – had they not, then renewal funding would not have been granted.

Both the Dial-a-Molecule and Directed Assembly Grand Challenge teams have adopted an inclusive approach to Network building, with each providing evidence of engagement with communities (academic and industrial) of 400+, including engagement with end-users at a range of levels. There is clear evidence of this, and patterns can easily be identified of which theme areas have the most mature such engagement.

Each Network has produced a Roadmap and Recommendations that span a range of potential actions and timescales, again strongly theme-dependent, some of which relate to core developments supported by end-user requirements:

- Directed-Assembly Roadmap

- Dial-a-molecule Roadmap

Both Chemistry Grand Challenges Networks have clear overlap with priority topics in the field of chemical engineering (e.g. 100% efficient synthesis and catalysis) and it should therefore help the retreat participants to see how such an approach might be useful to consider for the Engineering Grand Challenges.

**EPSRC Physics Grand Challenges – summary**

1) EPSRC, following community consultation in 2011, identified four physics grand challenges:
2) Two network grants were announced in 2012:

- Emergence and physics far from equilibrium – led by Dr Bogdan Hnat (University of Warwick)
  
  This diverse network aims to draw upon expertise from a variety of disciplines including plasma physics, materials science, mathematics and complexity science. Although very broad in nature, the network team aim to bring focus to the grand challenge by identifying unifying aspects of the dynamics for systems far from equilibrium such as spontaneous development of structure and patterns, dynamics of large-scale failures and responses to strong driving forces and shocks.

- Towards an integrated heuristic for understanding the physics of life – led by Prof Graham Leggett (University of Sheffield) and co-funded with BBSRC:
  
  Over the course of the 3 year network grant they aim to form new, cross-disciplinary research communities in which physicists and biologists work together and which involve academia, industry and other end-users. These communities will work collaboratively to identify the major research challenges in the physics of life, and in particular, to address the grand challenge of integrating biology across the length scales from molecules to systems.

3) The ‘Nanoscale design of functional materials’ Grand Challenge is being supported through via standard mode as well as via a range of initiatives including the ‘Big Pitch’ award – see http://www.epsrc.ac.uk/funding/calls/2013/Pages/brightideasawards.aspx

4) The ‘Quantum physics or new quantum technologies’ Grand Challenge is being addressed as part of the new EPSRC-led Quantum Technologies programme – see http://www.epsrc.ac.uk/research/ourportfolio/themes/quantumtech/Pages/quantumtech.aspx for more information.

Healthcare Technology Grand Challenges

EPSRC’s Healthcare Technologies theme is currently undertaking a community consultation in order to determine a number of Healthcare Grand Challenges on which they will base their strategy for the next spending review period. This consultation is aimed at understanding the opportunities within a number of healthcare focussed challenges for advances in computational, engineering, mathematical and physical sciences. The initial challenges were selected in collaboration with the Healthcare Technologies Strategic Advisory Team (SAT), and have been further developed to date through workshops with key stakeholders and users. A community web survey is currently open, to be followed by a key partner workshop.
in July 2014. A final list of Healthcare Technology Grand Challenges will be published early in 2015, after the agreement of the SAT.

As Healthcare Technologies draws on research and expertise from across the breadth of the EPSRC remit, we fully expect that a number of the challenges identified by the Healthcare Technologies theme will require significant input from Engineers, and it may be that some of their activities are run in conjunction with the Engineering theme. We are not suggesting that you should either intentionally avoid or focus on Health oriented Engineering challenges at this retreat; instead this information is supplied to help you understand the broader context at the EPSRC. It may be that health relevant challenges are identified by attendees at the retreat, and if so, it may be that we take these forward jointly with the Healthcare Technologies theme.

The initial ten Grand Challenges on which the Healthcare Technologies theme is gathering input are:

• Data analytics and digital infrastructure for healthcare;
• Enabling technologies for regenerative medicine;
• Engineering healthy behaviours;
• Functional enhancement for safe and independent living;
• Infection prevention and control;
• Patient specific treatment;
• Prediction and early diagnosis;
• Smart surgeries and therapies;
• Systems to support and improve healthcare provision;
• Understanding and interventions in neurological function.
### 8.5 Annex 5 - Future scenarios

<table>
<thead>
<tr>
<th>Best</th>
<th>Worst</th>
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| • Sustainable life  
  • Local balance of productivity / community  
  • Information world help  
  • Free, continual access to global state of support for e.g. medicine  
  • Ability to source or make all you need  
  • Environmental control  
  • Control of risk to health  
  • Best possible work/life, balance  
  • Space  
  • A sustainable world, no hunger, clean water for all,  
  • A stable world population  
  • Full filling occupations, technology to remove drudgery (e.g. household robot)  
  • Health and well being  
  • Replacement for antibiotics  
  • No cancer etc.  
  • No generic disease  
  • A caring society  
  • Access to education for all  
  • Virtual travel/ at least for business  
  • Space travel  
  • Nice weather  
  • Daily instant health MOT and cure  
  • Total equality  
  • Light – zero omission traffic  
  • Population stabilisation with a good quality of life  
  • Global co-operation  
  • Development of space for your benefit  
  • No pigeon holding of disciplines  
  • Carbon negative society  
  • Equity and access to water, food and energy  
  • Systems thinking design embedded in policy and society  
  • Environmentally aware society  
  • Wellbeing of individuals  
  • Balanced “local” working lining with global / distributed reach  
  • Able to use information – anticipate social stress, but to retain the meaning  
  • We have learnt to control consumption  
  • Wealth equality improved  
  • Work is meaningful and satisfying and balance of work and other life is chosen  
  • Community  
  • Abba and Bach  
  • ≤ 1 degree warmer | • Waterworld  
  • Toxic flooding  
  • Disease – including new ones  
  • No clean water  
  • No power  
  • Nuclear conflagration  
  • Radiation  
  • Sun  
  • Waste/failed nuclear/war  
  • Overpopulation – geopolitical tensions  
  • Global economic failure  
  • No transport  
  • Political extremism  
  • Robots in charge  
  • War  
  • Nationalism  
  • Fragmentation  
  • Famine  
  • No clean water  
  • Not sufficient food  
  • Plague  
  • Pandemics  
  • Man-made disease  
  • Death – of species  
  • New middle ages  
  • Collapse of public infrastructure  
  • Religious fundamentalism driving politics  
  • Reduction in education  
  • Global conflict breakdown in society  
  • Conventional  
  • Nuclear  
  • Uncontrolled/irreversible climate change bigger problems than we can engineer away  
  • Food  
  • Flood  
  • Heat  
  • Uncontrollable Disease New Pandemic akin to Spanish Flu  
  • Social breakdown  
  • Isolation (physical) – too much virtual world  
  • Fear/toxicity/hunger  
  • War, famine, nuclear disaster, lack of food/water  
  • V. poor quality of life |

---

**Note:**

- **Best** scenarios represent the ideal outcomes, focusing on sustainability, equity, and health.
- **Worst** scenarios highlight potential catastrophic events, including environmental and social upheavals.
<table>
<thead>
<tr>
<th>Valuing heritage / renewal</th>
<th>Stress, industrialisation, uncontrolled technological spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everyone travels a lower distance</td>
<td>War/nuclear winter</td>
</tr>
<tr>
<td>Security</td>
<td>More poverty/hunger</td>
</tr>
<tr>
<td>Privacy and identity</td>
<td>Divided society/inequality: gated communities and deprivation</td>
</tr>
<tr>
<td>Health / long living/ water, food</td>
<td>Runaway climate change. Natural disasters</td>
</tr>
<tr>
<td>Abundance of resources – reused</td>
<td>Pandemics – (no replacements for antibiotics)</td>
</tr>
<tr>
<td>Stable politics, economics, and population</td>
<td>“Big Brother” society</td>
</tr>
<tr>
<td>No “developing” reduction in equality</td>
<td>Population explosion</td>
</tr>
<tr>
<td>Re-connect communities</td>
<td>Complete deforestation – (exhaustion of fossil fuels without replacement)</td>
</tr>
<tr>
<td>Simple → apparently simple</td>
<td>Short lifetime of technological products</td>
</tr>
<tr>
<td>Richness of life</td>
<td>Rapid depletion of key resources</td>
</tr>
<tr>
<td>Global harmony /co-operation to solve world issues – culture of plenty</td>
<td>Redundancy/increased waste/energy use</td>
</tr>
<tr>
<td>Health and vitality</td>
<td>(not enough focus on what’s needed rather than possible)</td>
</tr>
<tr>
<td>Enjoyment and social contribution</td>
<td>Insufficient diversity for flexibility</td>
</tr>
<tr>
<td>Poverty – disease – conflict</td>
<td>Runaway environmental issues</td>
</tr>
<tr>
<td>Cheap clean energy, product ion exceeds demand</td>
<td>Managing population growth and aspirations proving impossible</td>
</tr>
<tr>
<td>Have more control and choice</td>
<td>Food and energy waste</td>
</tr>
<tr>
<td>Medical improvements robot medicine</td>
<td>Environmental Armageddon</td>
</tr>
<tr>
<td>Completely self-assembled</td>
<td>Political instability due to multipolar world</td>
</tr>
<tr>
<td>Manufacturing automation</td>
<td>Resource stress &amp; conflict</td>
</tr>
<tr>
<td>Social Freedom</td>
<td>Unintended consequences of technological development</td>
</tr>
<tr>
<td>Virtual Presence</td>
<td>Infectious diseases caused by DNA manipulation</td>
</tr>
<tr>
<td>Cheap transport</td>
<td>Asteroid strike</td>
</tr>
<tr>
<td>Economic development</td>
<td>Drowning in information – “virtual” has taken off</td>
</tr>
<tr>
<td>Social mobility</td>
<td>Resource wars &amp; increasing nationalism (Scotland celebrates 50 years of independence)</td>
</tr>
<tr>
<td>Reduce conflict</td>
<td>V. few super rich + slaves</td>
</tr>
<tr>
<td>Personalise active medicine – products and drugs through biological and cellular engineering</td>
<td>Majority unemployment/slavery</td>
</tr>
<tr>
<td>Biological engineering for techno-forming</td>
<td>No leisure/too much leisure</td>
</tr>
<tr>
<td>Intelligent, self – repairing, biomaterials (including electronic circuits which are (bio) cell generated)</td>
<td>Facebook</td>
</tr>
<tr>
<td>Increased quality of life through electrical. Mechanical, chemical and biological</td>
<td>Bee Gees + Stockhausen</td>
</tr>
<tr>
<td>Sustainable energy and resources at the planet level (with planet – level management</td>
<td>?°C warmer</td>
</tr>
<tr>
<td>Teleportation?</td>
<td>New build/replacement</td>
</tr>
<tr>
<td>Personality storage of restoration</td>
<td>Cameron still prime minister</td>
</tr>
<tr>
<td>Brian cloud / crowd?</td>
<td>Everybody goes to Eton</td>
</tr>
<tr>
<td></td>
<td>Everyone travels more and more</td>
</tr>
<tr>
<td></td>
<td>Vulnerability</td>
</tr>
<tr>
<td></td>
<td>We all speak with American accents</td>
</tr>
<tr>
<td>Least likely</td>
<td>Taboo</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>• Decarbonised and energy (inc. heat and transport)</td>
<td>• Logan’s Run @ 80? 40? forced euthanasia to “ensure” quality of life for all by enabling reallocation of juvenile resources</td>
</tr>
<tr>
<td>• No poverty</td>
<td>• Birth control compulsory</td>
</tr>
<tr>
<td>• No standing</td>
<td>• Reduction in variety of foodstuffs</td>
</tr>
<tr>
<td>• Social justice</td>
<td>• Animal research necessary</td>
</tr>
<tr>
<td>• No obesity</td>
<td>• Human genetic selection</td>
</tr>
<tr>
<td>• No additions</td>
<td>• Mental and physical health impacts of social networking technology</td>
</tr>
<tr>
<td>• World peace</td>
<td>• Social impacts of “Big Data” availability</td>
</tr>
<tr>
<td>• No arsenals</td>
<td>• Possibility of control/manipulation of data (Big Brother society)</td>
</tr>
<tr>
<td>• No social isolation</td>
<td>• Population growth control</td>
</tr>
<tr>
<td>• Respect for individual freedom and privacy</td>
<td>• Developing world will not develop</td>
</tr>
<tr>
<td>• Instantaneous travel</td>
<td>• → is it in our interest</td>
</tr>
<tr>
<td>• Resources from space</td>
<td>• Population management</td>
</tr>
<tr>
<td>• Global society equity</td>
<td>• Backlash against technology</td>
</tr>
<tr>
<td>• Egalitarianism trumps greed</td>
<td>• Restricted lifetime (rationing of resources)</td>
</tr>
<tr>
<td>• Success in Scotland</td>
<td>• Reverse role of women back to being only mothers</td>
</tr>
<tr>
<td>• Stability, resource sufficiency</td>
<td>• Should we try to cure everything?</td>
</tr>
<tr>
<td>• Technology solves social problems</td>
<td>• Genetic profiling (what do we really want to know)</td>
</tr>
<tr>
<td>• Peace</td>
<td>• 2064 – The United States of Europe</td>
</tr>
<tr>
<td>• The Off-side rule clarified</td>
<td>• Health and personality diagnosis at birth</td>
</tr>
<tr>
<td>• Microbial resistance reaches catastrophic level</td>
<td>• Fixed age euthanasia</td>
</tr>
<tr>
<td>• Total breakdown of infrastructure</td>
<td>• Death of privacy</td>
</tr>
<tr>
<td>• Humans controlled by robots</td>
<td>• Religion dominates politics – beyond fundamentalism</td>
</tr>
<tr>
<td>• Carbon-free energy generation</td>
<td>• Slim Scots prefer vegetarianism</td>
</tr>
<tr>
<td>• No changes whatsoever by 2060</td>
<td>• Purposelessness</td>
</tr>
<tr>
<td>• World peace and equality by 2060</td>
<td>• Wealth seen as a bad – GDP is not a useful metric</td>
</tr>
<tr>
<td>• Growth continues in unchecked</td>
<td>• The “….isms” all return / get stronger</td>
</tr>
<tr>
<td>• Disease eliminated</td>
<td>• Cynicism leads to withdrawal of public support for science and engineering</td>
</tr>
<tr>
<td>• Energy becomes cheaper</td>
<td>• The Ludites and fundamentalists win</td>
</tr>
<tr>
<td>• Every engineering solution is affordable solution</td>
<td>• Racism resurgence exacerbating social injustice</td>
</tr>
<tr>
<td>• Transport is ubiquitous and affordable</td>
<td>• Genetic engineering of humans for gain – Eugenics</td>
</tr>
<tr>
<td>• Peacetime</td>
<td>• The future “asbestos” scenario i.e. technologies “thalidomide” we were convinced were safe turn out to be lethal on a decadal time-scale</td>
</tr>
<tr>
<td>• Cheap, unlimited resources, with no “impact”</td>
<td>• Breakdown of socialisation / loss of social skills of the young because of IT</td>
</tr>
<tr>
<td>• No conflict, poverty, illness</td>
<td>• Democracy is failed model for development and social progress</td>
</tr>
<tr>
<td>• Global cooperation</td>
<td>• Increasing silo nation states, greater</td>
</tr>
<tr>
<td>• Reduction in energy consumption</td>
<td></td>
</tr>
<tr>
<td>• No disease</td>
<td></td>
</tr>
<tr>
<td>• Elimination of conflict</td>
<td></td>
</tr>
<tr>
<td>• Application of engineers /engineering</td>
<td></td>
</tr>
<tr>
<td>• Equality for all</td>
<td></td>
</tr>
<tr>
<td>• Identical to now</td>
<td></td>
</tr>
<tr>
<td>• Uniform / single system</td>
<td></td>
</tr>
<tr>
<td>• Greater diversity</td>
<td></td>
</tr>
<tr>
<td>• Off-world</td>
<td></td>
</tr>
</tbody>
</table>
**determination in big prospect e.g. China interface**
- Global cooperation impossible and technological progress is not possible on the big problem/challenges
- “Engineering life” (existing and pot-new)
- Genetic engineering – extension of life
- Should we cure everything
- Brain cloud?

<table>
<thead>
<tr>
<th>Most likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth/prosperity more uneven</td>
</tr>
<tr>
<td>• Major disease continue and additional new problems</td>
</tr>
<tr>
<td>• Energy is more expensive and rationed</td>
</tr>
<tr>
<td>• Big decisions about what problems to solve and what solution are implemented</td>
</tr>
<tr>
<td>• Wartime</td>
</tr>
</tbody>
</table>
8.6 Annex 6 - PEEST analysis

Political & Economical

- Encouraging and training new engineers – benefit economy
- Need to show “impact” (which may counter “blue skies”)
- Role of evidence – based on government
- Lack of trade support – selling of infrastructure to other countries etc.
- Short-term policies (election) e.g. flooding
- 30 years of industrial decline – policy choice to abandon production
- Rigidity of funding (schemes, league tables, ref....0
- “Normalisation” of engineering i.e. to ubiquitous
- No national engineering lab – communication with politicians
- No “Brian Cox” (thank goodness)
- Localisation of political effort
- Disillusionment with political leaders
- Splintering of engineering advice between different people / institutions
- Cronyism

Environmental

- Cost of resources
- Increase in process – decrease in availability e.g. critical list of elements – implications of digging up elements – political control of resources
- Escalation in consumption (western)
- How to manage demand?
- Businesses pushing for limited lifetime OK – move from making goods to servitisation
- Ideal middle class lifestyle
- Unsustainable (energy consumption) e.g.US
- Resources in general
- Embedded energy e.g. steel reforming, concrete (cement)
- Gets forgotten about
- Regulation not often based on good engineering to knowledge
- Farming – pressure on environment – food, security, efficient mechanised
- Nuclear – balanced need vs waste management – localise vs. globalism
- GM / animal testing → general public anti
- Genetics / design people / food selection
- Biodiversity – risk of losing it
- More sensors out in the environment – useful information out of data is problematic → Big Data – disconnect data / information
- Open Data
- Making data available can lead to public good
- Energy storage
- Taking responsibility about environmental impact (awareness)
- Waste management – recycling and re-use
- Engineering knowledge based upon sector they operate in e.g. construction
- Not enough energy to treat water
- Feeding the world - water from energy Nexus
- Drive for energy independence e.g. shale gas in US
• Climate extremes – becoming more prevalent
• Resource related political instability e.g. Arab spring – killing over food shortage
• Pollution of oceans -, plastics, acidity
• Space junk
• CO2 shortage/super enumeration – links to waste – localism vs. globalism
• What will people accept in their local environment vs. global environment
• Ethics/ green lobby → impact on perception of engineering
• Impact on energy – demanding sectors – public perception
• Regulation e.g. carbon tax – public perception of use of funding offsetting
• Whole life-cycle analysis / assessment – across sectors
• Reliance on other nations for energy supply
• Social implications of engineering solutions
• Bio-cumulating of poisons – toxic materials – toxins- people – environment
• Flipside – removing of toxic material may improve society e.g. reduce crime
• Legislation – e.g. smoking ban extremely successful – medical and societal.

Technological

What are we good at in the UK?

• Aero engines
• Niche energy
• Education & Research
• Design & Architecture?
• Drugs/Biotech
• Alcohol
• IT / Software
• Systems
• Military tech
• Process and industry
• Big data, information, here and now - smart meters, mobile devices, batteries
• Internet – online commerce shopping
• Functional materials
• Large scale computing
• Self-cleaning smart glass
• Regenerative medicines
• Aerospace
• Weather big sums
• Computing
• Models
• Medicine and medical devices – insulin
• Infrastructure resilience
• Monitoring – sensors everywhere
• Structural health
• Transport – road safety, road design, car design – post oil → electric cars

What aren't we good at?

• Automotive & vehicle
• Motorbikes trains
• Energy infrastructure + supply chain – renewable nuclear
• Scale up and commercialisation (volume)
• Entrepreneurship
• Physical infrastructure – technology – planning) e.g. high speed rail and motorways)
• Materials production and mining
• Consumer electronics
• Computer hardware
• Lack of supporting infrastructure for e.g. broadband coverage
• Food security – QA technology (quality assurance)
• Safe Society → CCTV, forensic science
• GCHQ and Hacking
• Connectivity

What has been/ will be most transformative?

• Mobile communications
• Need for analytic
• Wide varying applications
• Ubiquitous sensors and low power
• Medical devices / biomedical engineering → integration of multidisciplinary approaches e.g. of robotics, images registration, diagnostics
• Entertainment and leisure – behavioural change possibility? or risk from society – video streaming → TV on demand
• Social media impact on emotional development?
• Work life balance affected by mobility of technology and globalisation
• Infrastructure – fibre optics, mobile telephones, water, transport networks.
• Smart technology to exploit cement infrastructure
• Low power integrated circuits (on all the above)
• Limitations to future advances?
• New approaches e.g. quantum computing - spintronics

Societal

• Implications of lack of engineer in government (local and as well as nationwide) this also applies to top level companies
• Technology literacy
• The need to include younger engineers in key decision making
• Are engineers in the vs. avaricious or status seeking? (c.f. other countries) – they need personal characteristics
• Gender imbalance
• Lack of large companies in certain areas – foreign companies not investing enough in innovation in the UK
• UK good at operative industries – How can these be translated into engineering?, this varies from area to area
• These might move away from the UK
• Media / perception of engineers
• Public – understanding engineering in the everyday world
• Ethics in engineering - (e.g. weapon deployment)
- Global collaboration (also within the UK)
- Engineering input into wellbeing
- Engineering without boarders – need to encourage engineers to work to developing world challenges
- Engineering driving societal shifts (e.g. home working…)
- Having public discussion about new technologies (pros and cons) e.g. syn bio and Fracking – social acceptability
- Good engineering stopped due to public perception is negative
- Engage with the community – at school level
- Skills shortage → early intervention → work with teachers
- Definition of engineering – not just fixing things → promoting progress
- Broadness of engineering – common methodology, complex issues → smaller manageable societies
- Client base / also need to contribute to the impact of engineering
### 8.7 Annex 7 - From scenarios to themes

**Tentative emerging themes**

| • Enabling good health and well-being | • Enable clean water/energy  
| | o Sustainable energy provision  
| • Engineering life  
| o Engineering biological systems | o Renewable energy with realism  
| • Supply of good food at low cost | • Technology security and safety  
| • Towards a sustainable world  
| o Public discussion of direction of travel (cities)  
| o An environment for transport  
| o National mobility within a carbon budget constraint  
| o Dynamical networks, reverse engineering & design (Bio Nets, Brain, Virtual Nets, Transportation Nets, Elec Nets) | • Cyber & physical infrastructure  
| | o Stresses and breakdown  
| | o Vulnerabilities  
| • Autonomous systems | • Systems  
| • Multi-scale Engineering (scale up) | • Design/materials/manufacture/servitisation  
| | • Productive use of space  
| | • Risks associated with emerging technology  

**Barriers to overcome (T, I, S, M)**

- Technological
- Integration
- Societal
- Methodological

1. Engineering biological systems/Life + enabling health & well-being - T,I,S,M
2. Clean water, energy and food at low cost  
   Barrier is integration & societal acceptance Nexus (≠ developing world, developed world)  
3. Technology security & safety cyber & physical infrastructure - Integration is a barrier/societal acceptance is also a barrier  
4. Cross cutting themes
a. Integration
b. Scale

5. Systems
   a. Design/materials/manufacture
      i. Integration/methodology barrier

6. Autonomous systems/robotics
   a. Societal barrier e.g. acceptance of robots
   b. Link to Big Data/intelligent information
   c. Design of robust and best performance & resilient autonomous systems
   d. Capacity barrier

7. Other
   • ‘Multiscale’ Engineering – innovation across scales etc.
   • Close loop systems – Acceptability? Risk? Safety?
   • Manufacturing/process
   • Management of supply and demand
     o Materials etc.
   • Infrastructure
   • What is the next ‘inspirational challenge’ c.f. space?!
     o Is space still a relevant challenge?

Sector specific acceptability

Jobs being taken away – specific to sector e.g. different for manufacturing
Beyond the Molecule

THE CHEMISTRY GRAND CHALLENGE NETWORKS

The Directed Assembly Network (DAESTP)

Paul Raithby, University of Bath

PI of the DA Grand Challenge Network

E-mail: p.r.raithby@bath.ac.uk

Chemistry - The Grand Challenges

• EPSRC Initiative - Chemical Sciences and Engineering Grand Challenges
• Meeting in Manchester in November 2008
• Eols by January 2009
• Four Challenge Networks went forward to full bids August 2009
• Three funded by March 2010
• DAESTP Network started 1st April 2010
Chemistry Grand Challenges

- Utilising CO₂ in synthesis and transforming the chemical industry
  - www.co2chem.co.uk
- Dial-a-molecule. 100% efficient synthesis
  - www.dial-a-molecule.org
- Directed assembly of extended structures with targeted properties (DAESTP).
  - www.beyondthemolecule.org.uk

Our Vision

- To control assembly of matter with sufficient certainty and precision to create materials and molecular assemblies with far more sophisticated and tuneable properties and functions than are currently accessible
DAESTP Network

1. To form new research communities that extend beyond Chemistry and Chemical Engineering, and which involve academia, industry and users.
2. Identify research priorities and the major barriers associated with these.
3. The development of community driven research agendas resulting in highly transformative research with long term scientific impact.

DAESTP Network continued

4. To generate a clear road map which identifies priorities, barriers and intermediate targets that will justify the Grand Challenge in an inclusive manner.
5. To address the major societal and economic issues associated with the Grand Challenge and demonstrate the positive impact that progress in the challenge will have on these areas.
Network Champions

- PI - Prof Paul Raithby, University of Bath
- Co-I - Dr Harris Makatsoris, Brunel University
- Prof Lee Brammer, University of Sheffield
- Dr Neil Buurma, University of Cardiff
- Prof Neil Champness, University of Nottingham
- Prof Neil Hunter, University of Sheffield
- Prof George Jackson, Imperial College
- Dr Anna Peacock, University of Birmingham
- Prof Sally Price, UCL
- Prof Kevin Roberts, University of Leeds
- Prof Matthew Rosseinsky, University of Liverpool
- Prof Mike Ward, University of Sheffield
- Prof Chick Wilson, University of Bath
- Dr Sophia Yaliraki, Imperial College

The Network Coordinator

- Dr Jenny Woods
- Manages the Network
- Liaises with academics and industrialists nationally and internationally
- Manages the funding and award scheme
## Industry Participation

<table>
<thead>
<tr>
<th>Company</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>AstraZeneca</td>
<td>CCDC</td>
</tr>
<tr>
<td>BP</td>
<td>Creative Chemistry</td>
</tr>
<tr>
<td>GlaxoSmithKline</td>
<td>Infinium</td>
</tr>
<tr>
<td>Intelligent Formulations</td>
<td>Fujitsu</td>
</tr>
<tr>
<td>Johnson Matthey</td>
<td>Brychem</td>
</tr>
<tr>
<td>Pfizer</td>
<td>Fujitsu</td>
</tr>
<tr>
<td>Procter &amp; Gamble</td>
<td>TWI Ltd</td>
</tr>
<tr>
<td>Reckitt Benckiser</td>
<td>Xerox</td>
</tr>
<tr>
<td>Renishaw Advanced Materials (advanced coatings)</td>
<td></td>
</tr>
<tr>
<td>Bentley (advanced coatings)</td>
<td></td>
</tr>
<tr>
<td>National Physical Laboratory</td>
<td></td>
</tr>
<tr>
<td>Sirius Analytical</td>
<td></td>
</tr>
</tbody>
</table>

## Industrial Advisory Board

- GlaxoSmithKline
- AstraZeneca
- Pfizer
- Johnson Matthey
- Infinium
Our Network

- **Wide in scope**
  - five themes, each could easily be a grand challenge in its own right!

- **Wide in impact**
  - our materials have uses from healthcare to transport, from consumer electronics to construction

- **Truly Interdisciplinary**
  - across chemistry to engineering, biology, physics and mathematics

- **Progression across a research landscape, not a single path**
  - the ‘many pointed crown’, rather than ‘man on the moon’

Five Themes

1) Molecular Frameworks & Hybrid Materials
2) Crystallisation & Nucleation
3) Biological & Biomimetic Systems
4) Surfaces
5) Evolving Systems
Our Mission

- Stage 1: 2010-2012
- Build new research communities involving academia, industry & users.
- Develop community-driven research agendas, with long-term impact. Identify priorities & barriers.
- Present as a roadmap for future research.

The Network at the End of Stage 1

- 500+ members from the chemistry, chemical engineering, biology and physics communities.
- 15% of the members come from industry.
- Regular theme and cross-theme meetings
- Links with Synthetic Biology, Physics of Life Network, and with CPOSS and APS Groups.
- Published roadmap.
- Influencing activities - industry, funders, politicians
- “DREAMS” meeting for early career members.
Looking Forward and Building the 50 Year Roadmap

• 4 areas that will lead to advances over the next 5-10 years
  1) Development of Intelligent Reactors for synthesising and fabricating new materials (Emerging from Theme 5, Evolving Systems)
  2) Nucleation and Crystallisation Methodologies for making better Pharmaceuticals and Agrochemicals faster, more efficiently and controllably (Emerging from Theme 2, Crystallisation)
  3) Hybrid Materials for Environmental and Catalytic Applications (Emerging from Theme 1, Molecular Frameworks and Hybrid Materials).
  4) Manufacturing complex and hierarchical systems of biological functional materials (Emerging from Theme 3, Biomimetic Systems).
Structural Recommendations

- Enhance industrial/academic placement schemes to allow shorter and longer term exchanges
- Provide network opportunities for modellers and experimentalists to develop their areas in unison.
- Provide network opportunities to enhance the exchange of ideas between engineers, chemists and biologists.
- Ensure schemes are in place to train the researchers in the Directed Assembly area in the future - a Doctoral Training Network/Centre
- Arm the GC Network with funds to pump-prime short-term, developmental projects within its remit area
- Create a National Centre for Self-assembly and Functional Materials

Our Mission

- Stage 2: 2012-2016
- Keep on with all the activities from Stage 1
- Assist funders and community to take that research roadmap forward.
Creating & supporting communities

- Bringing the best people together & supporting their collaborative activities
- Networking meetings (9 p.a.), in-depth sandpits
- Summer schools
- Travel grants, up to £1k - 100 over 4 yrs
- Seed funds, up to £1k, to embed knowledge gained on travel back at home dept - 50 over 4 yrs
- Pump-priming projects - up to £15k, 4/5 per yr
- Mentoring, help with proposals & fellowships, etc
Creating & supporting communities

- Applications must be genuinely collaborative
- Must contribute to enhancing research in a theme or cross-theme area
- Often multidisciplinary
- Often arise directly from connecting with potential collaborators at our meetings
- Part of funding earmarked for Early Career Researchers
- Must be prepared to report results openly & acknowledge Network support

The Roadmap and Subsequently

- Built on the Roadmap Themes
- Theme 2
  - CrystallisAbility
  - Measuring Molecular Assembly
Inputs

- EPSRC
- Sandpits
- Manufacturing for the Future
  - Manufacturing
    - Advanced
    - Functional
    - Materials

Where MAFuMa fits in...

Synthesis, characterisation, theoretical understanding of materials.

Fundamental Science/Engineering research

Understanding, modelling and processing of materials and their behaviours

Incorporation of materials into processes, products and systems

Frontier Manufacturing

MAFuMa
Policy, practice & public

Policy:
- Input to Science Policy and Manifesto;
- "Molecules, microbes & mathematics” speech in front of Vince Cable in support of university research as source of innovation for manufacturing;
- Advocacy for chemistry & materials science at policy events

Practice:
- Close working with industrial colleagues, particularly around Theme 2;
- Links with NESTA’s Alliance for Useful Evidence & Parliamentary Office of Science & Technology;
- Working with Learned Society and Institute Groups, e.g. IChemE’s PTSiG

Public:
- Outreach Champions, science café events, etc

A Journal for Directed Assembly Ideas

Chemistry Central
Announcing a thematic series of papers publishing in Autumn 2014
Beyond the Molecule
Guest Editor: Paul Needs, University of Bath

- A series of papers on Directed Assembly Research
- The series is to pick up and exploit the assembly of matter with high functionality and precision to drive separations of materials and molecular assemblies - with a focus on applications in materials science and technology. It will include contributions from leading research groups in the field
- Publication will support the interdisciplinary community address the challenge outlined in the Directed Assembly Roadmap
- More details at: http://www.chemistrycentral.com/Beyond

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The Future

- Developing strong Theme leaders
- Follow through the Roadmap recommendations and targets
- Improve funding mechanisms for travel, seed corn and pump priming grants
- Continue to influence the science and manufacturing agendas through the Research Councils, Policy Makers and Stakeholders
- Develop the European dimension
  - COST actions in Themes 2 and 3

Acknowledgements

- Jenny Woods (Network Coordinator)
- The DA Champions
- The DA Community
- The EPSRC
- The Dial-a-Molecule Network Team (PI Prof Richard Whitby)
- The CO2Chem Network Team (PI Prof Peter Styring)
8.9 Annex 9 - Preliminary validation – view from independent experts

Risk and resilience in a connected World

Dr Richard Beasley, Rolls-Royce

How valid is the content within the GC?

• Content of the Grand Challenge is entirely valid with some missing elements;
• Need advanced knowledge of emerging behaviour (e.g. desirable/non-desirable vs. unexpected);
• Need to define modelling adequately (both analytical and abstract not either/or) – avoid modelling for modelling’s sake and focus on effective use and applications of model-based engineering. There is a need to continue to build modelling capability in the UK.
• Need to embrace uncertainty in order to control/manage it – answer question ‘does it matter if something is uncertain?’
• Need design for all through-life aspects;
• Making complexity comprehensible is crucial – not about making it ‘simpler’;
• Key issue is about embedding systems engineering as an approach that all engineers use – a lot of this is about education and culture change.

What opportunities does this Grand Challenge offer now?

• It will help suppress re-work and overspend e.g. French railway system debacle
• It will help embed a culture where projects are delivered on-time, on-budget and to the right specifications e.g. Heathrow Terminal 5, Olympics project.
• Recognise complex systems as an approach whilst understanding the barriers, particularly how to embed systems approach in the middle of a project.

What has already been done to address this challenge in the past and currently?

• Coordination is lacking – there are many enthusiasts about systems engineering and complex systems but no strategy as such.

What might be needed in the future?

• Standardisation of approach is required – need embedding into engineering education. RAEng report ‘thinking like an engineer’ is a good starting point but more needs to be done.
• Need further embedding of systems engineering approach at all levels e.g. product development.
• There is a need to educate engineers and programme leadership about how to plan and carry out iterations – need space in programme plan to react to what you are going to find.

How does this Challenge fit in the current UK and global context?

• UK industry getting into systems for value-added products and services – risk is that overseas firms doing things cheaper will learn the approach and ‘outgun’ the UK on the design front too. Plus side is that we have reputation for ‘value add’ and this will enhance it.

How adaptable is it to the future?

• Systems engineering approach enables projects and programmes to become future-proof. As an approach it will apply to anything in the future

• Embedding systems inc. complex systems approach in the development of new disruptive technologies is key – needs to be reflected in future investments (e.g. calls for proposals).

What can EPSRC do to address the challenge?

• Encourage systems approach to develop new technologies whilst being realistic in terms of timescales;

• Ensure that work on new technologies embraces the approach, to properly consider the issue of if one part changes (new technology) the surrounding parts need to change to accommodate the new technology – which may enhance or (more often, sadly) prevent exploitation of the technology potential.

• Focus on enabling researchers to learn how to make the outputs of systems engineering approaches re-usable for the future.

Prof Seth Bullock, Southampton

How valid is the content within the GC?

The challenge that is sketched (I would cast it simply as: coping with complex systems of systems) is valid in two senses: coping with complex systems of systems (i.e., engineering them, controlling them, managing them, securing them, etc.) is currently beyond the state of the art, and achieving real progress on this problem would be game changing. It would open new design spaces, new policy instruments, new regulation paradigms, new understanding of society.

What opportunities does this Grand Challenge offer now?

This GC has the potential to bring together, organise and cohere a community of researchers that is still currently quite fragmented and focus them on “systemic” problems that have real significance (finance, infrastructure, energy, demographic change, sustainability, resilience, the web, etc.). People problems are the most pressing challenges of this century: the physical sciences and engineering research communities need to be encouraged to tackle them head on in collaboration with the social scientists and humanities researchers for whom these problems are their home territory.
What has already been done to address this challenge in the past and currently?

The EPSRC has invested in complexity science over the last decade, targeting important applied contexts (energy, social science, infrastructure, etc.) as well as more fundamental areas (mathematics underpinning complexity). In Europe the FET funding programme has funded many projects at the interface between technology sector and AI/complexity. The EU flagship programme on Future ICT came close to being funded and would have targeted this GC (as part of a somewhat wider ambition to model all social systems).

What might be needed in the future?

The key factor (in my opinion) is maintaining the appetite for genuine interdisciplinary collaboration and ambition, but also managing expectations and not running before we can walk. The history of systems science (complexity science, cybernetics, soft systems methodologies, etc.) is one of repeated waves of excitement that break on the rocks of over-reaching hubris. Initial breakthroughs are over-played and expectations are raised. Then hard real-world problems are confronted and discovered to be much tougher to crack. Communities dissolve and funding is retargeted. As a result, we are still walking in the foothills of complex systems approaches and it will be hard to scale the heights if this kind of boom/bust cycle is allowed to continue. Setting a Grand Challenge is about targeting a peak that is currently out of reach, but it should also be about setting our sights on achievable base camps. Currently the GC text talks about predicting “behaviour in the presence of uncertainty, complex combinations of risk factors, and emerging behaviour”. This is very, very, challenging in all but the most trivial cases. In fact, in my opinion, an increasing focus on models that have predictive validity has tended to steer researchers away from making progress on understanding real-world complex systems towards large, impenetrable simulations with many parameters that can be tuned automatically in order to fit empirical data from the past with crossed-fingers that the model will also fit the unknown future. This type of big data modelling has made a lot of money for companies like Google, but if models are to inform policy or practice then policy makers and practitioners should be able (encouraged) to ask the models (and modellers) “why” questions (questions that Google don’t need to ask). Why does the model suggest that we should give up on High-Speed 2? Why will the proposed introduction of a “per transaction” tax on the stock markets improve stability? Why should the congestion charge zone boundary be changed in the way that the model is suggesting? Currently, we are allowing modellers to duck these questions if their models have good predictive validity (i.e., the models predict things that happened in the past) – this isn’t a good direction of travel.

How does this Challenge fit in the current UK and global context?

The language and ambition of the GC is consistent with thinking internationally. Systems problems are recognised as crucial in almost all challenging areas of policy and industry. It is true that the UK has a better research base from which to tackle these problems than some other leading research nations. I would say that complex systems research and systems thinking researchers in the UK are definitely amongst the leaders in the field. Also, there is also a positive attitude towards systems approaches in key UK industry – finance, infrastructure, technology. However, this window of opportunity will not last very long, I think. E.g., the interest in systems approaches in the finance sector is perhaps on the wane as the economy recovers.
How adaptable is it to the future?

Systems problems such as the ones articulated here will not go away. This grand challenge is here to stay.

What can EPSRC do to address the challenge?

I think funders have to move carefully. In this area: quality of proposals is hard to judge; project success rates are patchy; research networks, and multidisciplinary community building can result in talking shops and endless unproductive conversations about methodological tensions. Can something as nebulous as “systems problems” be a good grand challenge? Is the target specific enough? What would count as success? How will funders know which project proposals are central to the GC and which are free-riding? An alternative would be to identify one particular example of a very important “hyper-connected” problem and build a GC around that with the ambition to let progress on this problem ripple out to adjacent domains in due course.

Prof Hans Fangohr, Southampton

How valid is the content within the GC?

Most systems that matter in science and technology are complex: given examples include a jet engine, and climate, but also a liquid or a solid are complex systems in their own right: consisting of many atoms that on its own cannot do much but once there are enough, they can form a solid, a liquid or a gas: these phases are emergent phenomena. Such systems need to be described across multiple scales if we want to capture their complex behaviour: If a piece of metal is used in a structural context, engineers like to model this with finite elements (ignoring atoms) but in fact it is defects at the atom level that determine stability and propagation of cracks. Multi-scale modelling (in length and time), goes some way to allow more quantitative description of these systems. A jet engine contains many of such metal parts that interact to form an even more complex system.

Complex systems are thus of great relevance to EPSRC's remit.

What opportunities does this Grand Challenge offer now?

Understanding complex systems in real life applications is mostly done through simulation of the system (often in multiple steps of simplification).

In a nutshell, one creates a computational model of a complex system, then activates and de-activates particular interactions in the simulation model to research the importance and effect of these interactions and develop an understanding of the system. This is done systematically to get a better understanding of the system, and reduce its complexity as far as possible (irrelevant interactions can be ignored, for example). There is no silver bullet, and it requires scientist and engineers from all disciplines to interpret the acquired data to gain insight. The simulation models used will often have to cover multiple scales (length and time), or include different modelling paradigms.

This is a generic approach with wide applicability - improvements to the required multi-scale modelling have the potential to improve our understanding of many complex systems,
including many linking to the 8 great technologies, such as Advanced Materials, Robotics and Autonomous Systems, Energy Storage and Satellites.

What has already been done to address this challenge in the past and currently?

The UK has decent provision of computational facilities (in particular the supercomputer ARCHER). There is/was training in complexity (Warwick, Bristol) and complex systems simulation (Southampton) and training in next generation computational modelling (Southampton) through centres of doctoral training. The Institute for Sustainable Software is providing short courses to help to train scientists in (basic) best practice for software creation and use of simulation. There are other CDTs (such as Imperial, Cambridge, Oxford/Bristol/Southampton, and UCL) that focus on simulation modelling of particular complex systems (Materials, Chemical Sciences, Molecular Modelling and Materials Science).

What might be needed in the future?

Most complex systems are not tractable by analytical methods: outside a restricted set of problems of academic interest, simulation modelling is the key method to understand real world complex systems by systematic and virtual experimentation.

This is done through creation of simulation software that models a complex process. To increase the long-term efficiency of our efforts, such simulation software needs to be written to be well documented, tested, robust, easy to extend while maintaining testability, and thus be re-usable and extendable. This opens opportunity to use it across multiple scales and domains.

What will be needed in the future are robust software codes to address the multi scale simulation challenge required to understand (or at least handle effectively) complex systems.

How does this Challenge fit in the current UK and global context?

Modelling and understanding of complex systems, and use of that understanding and modelling capabilities to systematically optimise designs/products/policies is already used in many industries but up-take of such approaches is increasing with increased computational hardware power and growing international pressures to be competitive. Increasing the number of approaches and/or improving the training of those leading and carrying out the activity are very worthwhile.

How adaptable is it to the future?

The simulation modelling of complex systems will become more important in the future. Design optimisation is nothing else than exploring a complex system, this is of huge importance to industry, and a common application of (high performance) computing to improve insight, processes, products, and profit margins. The trend will continue.

What can EPSRC do to address the challenge?

A key method to solve complex systems challenges is the use of computer simulations. In fact, nearly all computer simulation work is studying complex systems: if the answers were obvious or obtainable otherwise, one wouldn't use simulation.
Simulation is based on developing and using code: we need focus on training for researchers to write robust codes, making use of state of the art techniques, develop trust in code so that other teams now and in the future will use it and make use of the investment.

It is now increasingly recognised that developing good software is a long term investment with great pay off (for example Tildesley report), and as the demand for complex systems simulation grows and computational resources become more affordable, the development of software to be used on those computational resources to understand the complex systems will grow in importance.

Investing into researchers and researcher-training in state-of-the-art computer simulation methodology to enable them to make best use of existing supercomputers is potentially more effective than investing more into bigger supercomputer: order of magnitude improvements are possible, and improved software and reproducible computational science skills will payoff for many decades to come.

Prof John Hogan, Bristol

How valid is the content within the GC?

From an engineering perspective, there are two ways of looking at the content of this Challenge. One is to ask how it can help understand, develop and improve current systems (for example, improve traffic flow in cities, without building new roads). The other is to ask how it can help design new products and services. Both could easily be addressed with this Challenge, but that is because it is so broad.

But neither will be helped much by it, since what is clearly lacking in either case is the human involvement. In the vast majority of complex systems, humans are involved at some point and their behaviour must be taken into account. Humans do not act rationally. They make judgements that need to be factored in to design, either of whole systems or of parts of a system. It is surprising that they are omitted from this Challenge.

What opportunities does this Grand Challenge offer now?

There are several examples mentioned in the text, where the Challenge could be exploited. But it is not clear from the question whether the emphasis is on the opportunities or the now. Assuming that the question is about the now and is asking what would make politicians stand up and notice, then here are some examples. Certainly badger-culling is a clear example of where an understanding of the complex connectivity between badgers, cows, TB and the environment would help resolve such an emotive issue (human involvement clear here? – when to cull?). Similarly, the rise in obesity and its link to diabetes could be addressed by the Challenge (is the rise inevitable, what causes diabetes, are obesity and diabetes linked causally, why do people eat so many burgers?). Then there is the whole question of how we use our healthcare system. Should people be charged to visit their GP? Would that lead to a more healthy population (since then GPs could focus on the really ill and not have to deal with hoards of worried well) or to a less healthy one (as the poor ill fail to visit)? What is the best arrangement of primary, secondary facilities (should our GP services include x-rays etc, but then there would have to be fewer of them, further away)?

What has already been done to address this challenge in the past and currently?
EPSRC has done a really great job in investing in Complexity Sciences, with a lot of capacity building. There are now many PhDs out there, in academia and industry, with a systems approach (based on quantitative methodologies, not just talk) and who can interact with people from many disciplines. This will bear fruit over time, provided it is tended and watered properly. But the tendency will be for them to go native, so work needs to be done here.

What might be needed in the future?

It depends on the level. At a political level, it seems to me that education is key. Too often, you hear politicians claiming all sorts of things about systems, in the absence of any evidence (e.g. effectiveness of PFI schemes). Of course, this is all ideology, dressed up as logic. So education of politicians is probably not going to be effective (their minds are already made up). No, I am talking about educating the public, newspapers and the media. Here people need to be given tools to challenge decisions made in our name. At the moment (e.g. climate change), facts are so well hidden that people do not know what to think. So EPSRC should get involved in education, working with schools and the media to get the message out (the EPSRC YouTube channel is a start, but its effectiveness is limited, unless you like chocolate printing).

Then EPSRC needs to keep in touch with its Complexity graduates and ensure that they are keeping up knowledge of what is new in the field.

How does this Challenge fit in the current UK and global context?

It is central to policy making, to economic development, to society. It is a big one and one that we can do something about, in the (relatively) short term.

How adaptable is it to the future?

Well, you could argue that this Challenge has always been there and always will be, so it is definitely future proof. The problem is that unless some clear and measurable progress is made, people will lose interest or say that it is way too hard.

What can EPSRC do to address the challenge?

The problem with this challenge is that it is way too big and has too many EPSRC stakeholders. In one corner, you have the engineers who know the problems, but need solutions quickly. The bridge needs to be built and they can’t wait for some fancy theory (& besides, they know how to build bridges). Then you have the physicists, who will claim that, since they invented the laser, they should be allowed to tell engineers what to do. Then you have the mathematicians, who need something nice to prove. Finally you have the computer scientists, who know that it can all be done on a big enough computer, as long as everyone is trained to program a GPU. There are no social scientists in EPSRC, so it is going to be difficult.

So EPSRC needs to do some serious thinking about its structure and how it interfaces with the outside world. Essentially, the Challenge as outlined in the document that I was sent, is too big for EPSRC. It needs serious, sustained, involvement from two other communities. I have already mentioned the social scientists (to take care to the human involvement). But also you need the public stakeholders (individuals, communities) who need to be educated.
The only way forward that I can see is to take parts of the challenge and to create groups of stakeholders who will need to work together over extended periods of time to try to come up with solutions to those parts. I can see no “one solution fits” all (yet). Instead the problems should be leading the solutions, not the other way around (which is what it feels like at the moment).

Prof Colin Taylor, Bristol

How valid is the content within the GC?

The content is valid. Given the complexity of the complexity topic itself, we can expect that there will be many currently unknown issues that will emerge as we dig deeper into it.

There are countless applications across engineering, human organisations, ecology etc where complexity exists and has potential to be exploited to do good or to prevent bad. We are nowhere near mastery of the topic, either in just characterising it or being able to exploit it purposefully. However, I would say that we are now starting to appreciate the potential of such mastery. At present, we tend to design systems to eliminate complexity, making them complicated, and thereby more easily managed, rather than complex. Eliminating complexity will always be a useful strategy, but if we can manage complexity too, then this will open up new horizons to generate better value solutions.

There is a book “Surfing the Edge of Chaos” by Pasquale which argues that achieving a state of controlled chaos is the best way to promote change in complex organisational systems because at that point both the impedance to change and the imperative for change become congruent. The challenge is to control the chaos purposefully so that you can steer the system into a new desired state without it escaping to a failed or undesirable state. Whilst Pasquale argues from a business dynamics perspective, I believe the underpinning concepts are universal.

Taking a system (be it organisational or a physical system) through such a state change requires courage, knowhow and great resourcefulness, since one has to continually sense the state and apply adaptive energies to steer it in the chosen direction. Effectively, in doing this, you are reshaping the system’s performance space (essentially its complicated, multi-dimensional potential well) so that the system moves to a more desirable location in the performance space whilst at the same time you are reshaping the local topography of that space (the potential well location, shape and extent) such that it ‘captures’ the system response in a safe and desirable region. In doing this, you are applying energy to change the system. The challenge here is to co-evolve the performance space and response trajectory. Imagine a ball resting on a stretched sheet or membrane. If the ball is at rest, it will be at a locally low point in the membrane (at the bottom of a potential well). If we want to move the position of the ball, we can reshape the membrane so that the ball starts to roll in the direction we want it to – i.e. we are moving the position and shape of the local potential well which the ball automatically follows until we have reshaped the membrane so that the local potential well is now where we want it and is deep enough to keep the ball there. Now imagine doing this for a real system that has thousands of dimensions, control parameters and response variables (hyperspace); there research challenge is to master this scale of system.
If you can move the system towards a chaotic state, when it becomes sensitive to smaller changes in input and output energies, then you have entered a very energy efficient transition state. However, given the low impedance and high sensitivity, the system can suddenly channel much of its energy into a trajectory that leads to an undesirable state. At that point you need an energy reserve of high power that you can apply quickly to correct the trajectory. This is an important component of what I mean by resourcefulness; you need appropriate sources and control of energy and other resources, plus the knowhow and capability to apply the corrective energies and resources. But this does lead you to energy efficient solutions which you hope to make stable.

I see the above as purposeful designing of the system dynamics (which is why I describe our work at Bristol as ‘Dynamics Engineering’ rather than ‘Engineering Dynamics’). My view is that we are still in the very early days of understanding how to exploit complexity and a long way from being able to use it as a matter of course in engineering or other domains.

Two key questions embedded in the above are: ‘How do we decide where a new desirable state is?’ and ‘How do we find the most energy efficient trajectory to that state?’ Both these questions are about Value. Why is it Valuable for us to get the system into the new state? The answer is because the new state enables us to do something useful that we otherwise couldn’t. Taking the National Infrastructure renewal challenge as an example, we need to find value gains or cost savings of tens or hundreds of billions of pounds in the UK alone. I see this as moving the complex infrastructure systems into new parts of their performance space that we have identified as yielding better value to us, i.e. the SERVICE that the infrastructure provides is more useful, while the energy expenditure (proxied by cost) to get it and keep it there is affordable and sustainable. I see understanding of Value within this complex system landscape as a key component of complex systems mastery – if you know why it is desirable to get the system into a particular state and know how to navigate to there, then you have the means to realise the value.

Systems thinking tells you that a systems’ disproportionate value rests in the connections between the components, not in the components themselves. So I believe that value laden system design depends on understanding what connections to put in place so that you can shape the performance space to navigate the system to a desirable position within it.

What opportunities does this Grand Challenge offer now?

Sustainability reduces to human beings learning how to behave sustainably as individuals and collectively in their necessary collaborations. We learn continuously and automatically in everything we do, and we adjust our behaviours through our learning. The environments we create shape our behaviours; they enable us to do some things and constrain us from doing other things. To live sustainably we need to reshape our environments to enable us to do sustainable things – i.e. to promote sustainable behaviour. However, people are active, capricious components of their environments, which introduces complexity and the need to attain mastery over it.

I believe complex systems thinking has to be at the heart of how we think about and create societal resilience, of which infrastructure resilience is an integral part. Regarding the latter, I believe we have the wrong focus on the infrastructure assets. Resilience is actually about resilient human behaviour, which is enabled by the SERVICE that the infrastructure offers.
The service is fundamentally about enabling resource flows and transformations, where the resources are essentially energy carriers. The infrastructure enables us to move resources (energy) to where we need it and then transform them (energy) into useful work, which we value. An alternative perspective here is that we are looking at the resilience of supply networks, which are enabled by infrastructure (and the people embedded in the infrastructure systems).

Resilient behaviour depends on awareness of context, awareness of your situation within that context, clarity of purpose (i.e. what outcomes you want to achieve) and having sufficient resourcefulness to design, create and navigate towards a value laden solution (desirable outcome). This is complex systems mastery. Taking earthquake resilience as an example, imagine the Tohoku Japan earthquake. We could only know what had happened after it had happened (extent of damage, tsunami, Fukushima etc). We had to learn rapidly about what had happened (situational awareness), determine our purpose (survival, relief, recovery, re-establishing critical supply networks to deal with Fukushima etc), then apply our resourcefulness adaptively and creatively to get to more desirable situations. That process is still ongoing in Japan. The same process happened and is happening in the Somerset Levels flood event. Imagine these events 50 years ahead of now, when we are likely to increasingly depend on increasingly pervasive ‘smart’ technologies – making these systems robust and resilient will be essential – imagine how ‘dumb’ we might suddenly make ourselves if these smart systems collapse as a result of an earthquake or other natural catastrophe!

What has already been done to address this challenge in the past and currently?

I believe that the fundamentals of complex systems have been developed sufficiently for us to start exploring their application to real world problems (and indeed many researchers are doing this). That is not to say that all the fundamentals are well understood – far from it. Exploring real world complexity will help us understand gaps in fundamental knowledge and understanding that we need to fill. It will also inspire further exploration of the fundamentals.

From my infrastructure engineering perspective, I can see early forays into the application of complex systems thinking, which are starting to reveal the potential value of their application, but we are nowhere near mastery and being able to frame such mastery so that it becomes a standard tool in an engineer’s resourcefulness.

What might be needed in the future?

If we are to develop mastery of complexity, we need to enable ourselves to explore the problem theoretically, computationally, in the laboratory and, crucially, in real-world situations. Theoretical, computational and laboratory models are abstractions of reality, simplifying the real world so that we can explore aspects of it. Such abstraction is absolutely essential if we are to learn effectively and efficiently. However, the very nature of complexity is that it is sensitive to the system’s features and details, so we must be able to do real-world studies in order to validate and elaborate the models. Therefore, living laboratories (e.g. the city as a laboratory, with people and organisations being co-producers) are essential enablers of research and practice.

We need to ensure that we have an integrated portfolio of theoretical, computational, laboratory and real-world research enablers so that we can choose the appropriate tool to
study particular aspects of the problem and connect that study to other developing strands of knowledge and understanding.

How does this Challenge fit in the current UK and global context?

It is absolutely essential and I believe is the source of the scale of value gains the UK and global economies need to achieve.

How adaptable is it to the future?

It is the future!

What can EPSRC do to address the challenge?

Support the notion that mastery of complexity is a very long term game (50-100 years).

Keep fostering the multidisciplinary community that is needed to achieve mastery (research through to industrial, commercial and societal application). This means seamless connections between the research councils. Disproportionate value gains come from the connections between the councils.

Keep developing the portfolio of research enablers.

Build linked critical masses of researchers (PhDs and EngDs) exploring complexity in different application contexts but building a common knowledge, understanding and methodology base. EngDs are particularly valuable bridgeheads into real-world studies.

Controlling Cell Behaviour

Prof Serena Best, Cambridge

How valid is the content within the GC?

Extremely valid. Significant developments in the treatment of a range of chronic diseases will be achieved if sufficient effort is put into this area. The UK is very well placed with a number of leading research institutions and industries able to advance the field.

What opportunities does this Grand Challenge offer now?

There are a number of diseases that are not currently being addressed adequately, but which would benefit significantly, even in the short term, from investment in this area. There are clear opportunities for university spin outs, and university-industry partnerships, particularly in the areas of:

- Structures and scaffolds for cell guidance for regenerative medicine
- Bioreactors
- Improved understanding of biochemical cues that control cell behaviour
- Sensors, new diagnostic techniques, and related data handling and analysis methodologies to support design of devices and materials for cellular control.

What has already been done to address this challenge in the past and currently?
There is significant amount of work on-going in the field. However, the issue is to ensure that the research is shaped into a form that can be translated into clinical application.

What might be needed in the future?

One of the issues here is that there is a need for the regulatory framework to keep up to date alongside the new developments that are taking place. Another issue is that there is a significant funding gap between in-vitro and (the much more expensive) in-vivo validation work that needs to take place. The development of methods to control of cell behaviour in-vitro which mimic more closely the environment in-vivo would be ideal. However, it needs to be recognised that industrial take-up relies on evidence of in-vivo efficacy and safety.

How does this Challenge fit in the current UK and global context?

There is a huge strength in the UK in this area. However, in order to remain at the forefront on the field and to ensure that a wider range of disease states can be treated, it is essential to ensure that adequate support is given both for fundamental research and also for research which is suitable for more rapid translation.

How adaptable is it to the future?

The ideas are highly adaptable and the learning that is achieved in one area is likely to be applicable to several others. I see this as one of the key, underpinning areas of research that should be funded at this time.

What can EPSRC do to address the challenge?

It would be good to refine further the sub-themes within the overall Grand Challenge, to identify short, medium and long-term objectives for each of several key therapeutic targets. Once this is done, I feel that the idea of a Network or a Hub in these areas should be explored, to bring together the leading research centres in the UK. In addition, I agree fully with the summary document which suggests that end users and other stakeholders should be engaged at an early stage.

The question is raised whether the UK has suitable infrastructure and facilities available at present. This should be addressed as a matter of urgency and the idea of a central equipment / test facility with key, but quite specialised equipment might be investigated.

Prof David Bogle, UCL

How valid is the content within the GC?

The challenge is significant, important and one where the UK has a strong position with potential to lead in parts of the scope.

My key criticism is that it talks about cells and not cell populations. Therapeutic and industrial challenges will involve the engineering of populations of cells, not just individual cell behaviour. Cells, whether free or connected, communicate through molecular and ionic exchange (and probably through other means) and this is part of the engineering challenge. This needs to be woven into the document. The title alone is problematic: perhaps better ‘Controlling the behaviour of cells and cell populations’. Fifth bullet on first page could also include ‘for control of cells and cell populations’.
A second item that should be mentioned is uncertainty. The systems are so complex so we can’t include all we know and there is much that biologists don’t as well. You could argue that it is part of system engineering but I think it needs a specific mention.

Stakeholders is a big term here and perhaps you should be more explicit. It includes not just industry but also healthcare (not usually seen as an ‘industry’) and the wider community who are concerned about what new technologies can do and what the risks are.

What can EPSRC do to address the challenge?

Networks (linking engineers/physical scientists with an interest (there is a Biomedical Systems Community run by the RAEng) but also across the various stakeholder domains), training grants, support of new curricula development, as well as traditional grants. Perhaps most important is to develop collaboration and support with other RCs especially BBSRC and MRC. This is an area which routinely falls between the Research Councils as each tries and identify what is distinctive to their domain and yet the challenges cross the boundaries. The area is so large big area that it should not be too concentrated.

**Dr Susan Rosser, Edinburgh**

How valid is the content within the GC?

The content is very valid but very broad. This breadth is both a strength and a weakness. There are potentially a vast number of applications – many we will not even think of but will become possible as technology develops.

What opportunities does this Grand Challenge offer now?

- Highly multidisciplinary – a great strength with potentially highly innovative exciting work at the interface of scientific disciplines.
- Taking engineering approaches into biological sciences which has already been initiated in the synthetic biology field but can be expanded into many other biological sciences disciplines.
- There is also the exciting opportunity for engineering to learn from biology. Learning by building might identify new engineering challenges and new ways of addressing them (this has not really been properly engaged with yet)

What has already been done to address this challenge in the past and currently?

Synthetic biology roadmap and the array of subsequent RCUK and TSB opportunities. These opportunities are fantastic for the research community however - in my opinion there has been far too much emphasis on the industrial biotechnology agenda to the detriment of engineering approaches (I am from a biotech background).

What might be needed in the future?

More biological tools particularly for multicellular systems. The vast majority of work to date has focussed on microorganisms. To impact on agriculture and theranostic approaches a whole suite of biological tools for plant and mammalian cell engineering needs to be developed urgently. Currently they simply do not exist – we need the ability to control gene
expression etc in reliable, predictable, orthogonal and tuneable ways. The potential for impacting on human health could be vast if we could engineer in vivo diagnostic and therapeutic cell lines. The ability to reliably programme stem cells have enormous implications for regenerative medicine and the ability to engineer cell lines for high levels of production of expensive pharmaceutically important biologics (e.g. antibodies, nanobodies etc.) has implications for affordability of treatments.

Interface with electronics – we need to be able to measure and control cell interactions with electronics for sensor applications and a whole range of biomedical devices. We would like to read electronically what is happening within cells and electronically programme cells. We would like to do this in real time.

Engaging with different forms of engineering in addition to control engineering. In particular I would like to see more engagement with electronics engineers.

The data produced by analysing cellular processes requires new software engineering.

Also a neglected area is in the automation of biological processes. If we want to make biology an engineering discipline then we need better ways of automation e.g. one near term problem is the automation of DNA synthesis – currently there is too much reliance on human techs. This is essentially an engineering challenge that should be addressed by engineers to ensure that robotic hardware can communicate and link with each individual step. Process engineering?

Make use of new tech e.g. 3D printing and equipment of that tech specifically in the context of controlling cellular behaviour or building biological systems.

How does this Challenge fit in the current UK and global context?

Extremely well. It fits squarely within the synthetic biology, regenerative medicine, agri-tech and new advanced materials of the eight great technologies and also impacts on big data and robotics. There are also very many EU, US and Asian initiatives in this area both collaborative and competitive.

How adaptable is it to the future?

I would say that not only is it adaptable to the future it has the potential to change the future.

What can EPSRC do to address the challenge?

Fund some multidisciplinary programme grants in this. It is such a big complex challenge that individual project grants will not impact sufficiently. Also in my opinion joint grants with the BBSRC won't address the area adequately either because of the different agendas and cultures of the research councils.

Take risks on developing new potentially disruptive tech aimed at biological systems. High risk-high gain.

**Prof Rachel Williams, Liverpool**

How valid is the content within the GC?
I think this is an exceptionally valid Grand Challenge. I believe there are very significant opportunities to be gained by bringing together engineers, physical and biological scientists and clinicians in integrated cross-disciplinary groups firstly to define the research questions and the ‘real life’ problems and secondly to develop the new approaches and schemes to address these issues.

I think there are very high quality researchers in EPS and biological sciences that do not necessarily identify themselves with this cross-disciplinary area and this Grand Challenge could help to encourage them to engage in this area and thus make a substantial contribution to take this field forward.

I think the potential impact of the output from this Grand Challenge is enormous both societally and financially.

What opportunities does this Grand Challenge offer now?

There are a number of groups within the UK already engaged in this cross-disciplinary area and this Grand Challenge would give them a forum to enhance their collaborations bringing in new expertise where and when required. This would give the Grand Challenge a ‘running start’.

Bringing a selection of these groups together may help to share good practice and identify what works and what doesn’t work so well and then use this to develop more effectively.

Establishing this Grand Challenge could immediately help to encourage engagement from end users, both commercial and clinical, through an understanding of the commitment to the field and thus its underpinning.

What has already been done to address this challenge in the past and currently?

There is existing and previous funding allocated to this field, in particular to my knowledge, in biomaterials, medical devices and regenerative medicine. These have resulted from specific thematic calls as well as responsive mode funding. This has given the field some existing presence and reputation. I believe this underpins the Grand Challenge and gives it an excellent spring board from which to build a far greater presence in terms of breadth and depth.

What might be needed in the future?

I believe that the major hurdle to the Grand Challenge, in particular in the healthcare area, is how to progress the excellent cross-disciplinary science that occurs in the laboratory into clinical practice through the regulatory requirements. It would be really helpful if this Grand Challenge could help to identify the pathway through this process from the outset. If the researchers understood these requirements and the research was undertaken within this framework from the start it might facilitate its uptake at the later stages and encourage the input from commercial and clinical collaborators.

How does this Challenge fit in the current UK and global context?

The UK has internationally recognised researchers working in this field, however, other countries are also putting significant investment into this area. Thus if the UK wants to
continue to be competitive in this area it is essential to continue to invest and ideally increase its investment.

One of the advantages this field has in terms of outreach, in particular in the healthcare area, is that the public generally have some understanding of the potential of the output. I believe we should take advantage of this in relation to its context in the UK.

How adaptable is it to the future?

The remit of this Grand Challenge is broad and its cross-disciplinary nature makes it highly adaptable to future challenges. The key to this will be engaging the correct people with the appropriate skills.

What can EPSRC do to address the challenge?

Firstly, EPSRC could help identify the key people already working in this field and particularly those that could engage other key players that are not already interacting in this area.

Secondly, I believe there will be a need for core facilities to provide state of the art analysis techniques available to all involved in this Grand Challenge. This could be data/image analysis, biological (microscopy, biochemical) analysis, high throughput testing, computational modelling, regulatory compliance etc.

Thirdly, I believe we need to develop the next generation of scientist to be the future leaders in this field through mentoring and support (academic and financial).

Engineering from Atoms to Applications

**Prof Adisa Azapagic, Manchester**

How valid is the content within the GC?

The content is valid but it fails to mention that it must be addressed with sustainability in mind (see other answers for more detail).

What opportunities does this Grand Challenge offer now?

We have an opportunity to design new products and systems which are much more sustainable – economically, environmentally and socially – than today. To effect this, it is essential to take a life cycle approach, from ‘cradle to cradle’, to avoid shifting sustainability impacts along the different scales and supply chains. It is also important to start thinking about design for providing service rather than selling products at very early stages of design (at the atom or molecular level onwards) to ensure meeting human needs in a much more sustainable way in the future.

What has already been done to address this challenge in the past and currently?

There are some emerging attempts to bridge the different scales both in the UK and internationally, but as far as I am aware, none in the sense I’ve outlined under question no.2.

What might be needed in the future?
Please see the answer to question no. 2.

How does this Challenge fit in the current UK and global context?

Designing across the scales with sustainability in mind will help address many global as well as UK sustainability challenges, such as improved resource efficiency and securing of supply, reduced waste, climate change mitigation, economic growth, health and safety, etc.

How adaptable is it to the future?

As long as generic and flexible methodologies and approaches are developed, it should be adaptable to the future.

What can EPSRC do to address the challenge?

At the risk of stating the obvious: providing funding for addressing this challenge. Possible mechanisms include a managed programme, fellowships and DTCs.

Prof Duncan Lockerby, Warwick

How valid is the content within the GC?

The identified Grand Challenge is extremely valid – it identifies a wide class of modelling challenge and technological opportunity that will be presented to academia and industry over the next 20-50 years. The design of products and systems that benefit from a molecular or atomic knowledge/modification necessarily requires a sophisticated and generic multi-scale multi-physics modelling framework. This relates to all phases of materials (e.g. liquid, solid, gas).

I wonder if the title “Designing across scales – products and systems” implies a ‘design’ focus that is not intended from the content of the document. I think a broader title such as those suggested in the document, might better reflect the full scope of the grand challenge. From my understanding of the document there are three distinct aspects to this grand challenge: modelling, simulation and design. The ultimate goal is the design of new products and systems, but it might be better to explicitly mention all three in a title or in the document e.g.: “From atoms to applications: modelling, simulation, and design”

What opportunities does this Grand Challenge offer now?

Addressing this grand challenge will transform our design capability, where the molecular/atomic nature of the solid/fluid plays a fundamental role in determining the performance of the product or system. These products and systems are the opportunities (possible examples are given in the document). The other opportunity is in transferring these multi-scale modelling approaches to multi-scale systems outside of engineering.

What has already been done to address this challenge in the past and currently?

In terms of fluid dynamics, in the UK, the Programme Grant "Non-equilibrium Fluid Dynamics for Micro/Nano Engineering Systems", represents to date the most significant EPSRC investment in modelling non-continuum fluids (i.e. where the molecular nature of the fluid must be taken into account in order to make large-scale accurate simulations). So far, this has made a number of significant advances in multi-scale modelling for fluid systems.
What might be needed in the future?

- Robust, generic and efficient multi-scale methodologies and highly-skilled researchers to develop them.
- Access to major high-performance computing resources
- Software tools, for future designers of systems and products to use, and highly-skilled scientific programmers to develop them.

How does this Challenge fit in the current UK and global context?

The UK has existing capability in this area, in terms of molecular and atomistic simulation, it also has a growing capability in connecting these microscopic models with macroscopic ones (see the Programme Grant mentioned above). It is therefore in a very strong global position to tackle this Grand Challenge. What is required, as mentioned in the document, is aligned thinking, communication, and ‘buy-in’, across the various disciplines.

How adaptable is it to the future?

My interpretation is that the Grand Challenge is general in terms of potential applications. Referring back to my suggested title: “From atoms to applications: modelling, simulation, and design”. There are myriad potential and as yet unknown design applications that might present themselves over the next 20-50 years that require an atomic/molecular consideration. The essence of this Grand Challenge is to create design computational design tools that are generic enough to deal with them and harness their full potential.

What can EPSRC do to address the challenge?

- As discussed in the document, up-skilling in this area is key: e.g., masters and doctoral training
- High-performance computing provision
- A research network would be extremely useful
- Fellowships (at all levels), to attract and retain the highest-calibre researchers to the UK

Prof Paul Shore, Cranfield

How valid is the content within the GC?

The constructed Challenge encapsulates broad technical / production concerns relating to how small features/particles can be effectively distributed onto larger components. The range of issues and applications is likely to be broad and involve a number of key industrial sectors appropriate for the UK in regards impact and wealth generation. The opportunity areas presents good training subject areas and presents demand to develop new engineering skills and tools.

What opportunities does this Grand Challenge offer now?
I would imagine the opportunities include: emerging electronics, medical devices, renewable energy systems, aerospace surfaces for aerodynamics and engine efficiency as well as for the automotive sector. Intelligent "Coatings" for many components can be expected as well as instrumenting components via inter-active surface based features/devices.

What has already been done to address this challenge in the past and currently?

Plastic electronics processing including inkjet technologies, Sol Gel methods, TFT methods, vacuum multilayer coating for activated devices, UV and IR coatings, textured film technologies for light handling, microbiological retarding film, thermal barrier coatings with internal sensors, aerodynamic intelligent surfaces. The Ultra Precision CIM is clearly defined to be operating all across the length scale range. The Ultra Precision IKC was similarly defined. CIM's in large area electronics and advanced metrology are also active in this domain.

What might be needed in the future?

Ability to produce cost effectively. This aspect needs the UK to reconstruct its production machine tool sector by pulling existing companies into new sectors and helping grow new UK machinery / instrument companies. The equipment might be systems for coating, applying small features, particles or even growing structures, or creating features through layers/laminations. I personally would prioritise GC that have elements (even if embryonic) of a value/supply chain with key UK elements of novelty or added value. Otherwise these GC simply alert everyone of direction settings.

How does this Challenge fit in the current UK and global context?

I think this is a very broad subject matter that will allow many applications from diverse sectors. A common demand will be producing and measuring demands across the various length scales and 3d shaped components. As mentioned in the GC document the UK has already created research infrastructure that is, or could be tuned into attention of this Grand Challenge focus. Many of the CIM centres and the CDT's could contribute.

How adaptable is it to the future?

I would think the GC as described is reasonably future proofed. It might be rather all encompassing and therefore simply a headline or strap line for research at different length scales: which might be fine but it is not a down selecting in itself.

What can EPSRC do to address the challenge?

I think EPSRC could best make an open call collate responses. Review and respond with targeted opportunities to respond that are led by the PI's of the better outline submissions. In this way EPSRC can have an open call but perform some channelling to ensure facilities and capable centres are draw in to ensure specific GC projects are not stand alone but somewhat integrated to the existing facilities. Suggesting outline proposals with DTA's from CDT already allocated might be a wise mechanism to draw out new ideas from all whilst still pull in the expertise of the groups operating CDT's.

Avoid funding GC with wordy deliverables. A GC should be grand enough to recognise in hardware or demonstrable functionality.
Bespoke Engineering

Dr Clive Badman, GSK

How valid is the content within the GC?

The content is valid, but perhaps not comprehensive. Bespoke engineering could for instance contribute to real-time diagnostic factories for detecting and reacting to environmental or health conditions. Food processing also may be a significant opportunity (given the distribution of farms and gardens). One of the bigger opportunities is repair and replacement of parts for equipment, which can often be obsolete or have a long supply chain. Another opportunity would be in new responsive supply chains to meet the needs of stratified/personalised medicines – possibly linked closely with diagnostics.

What opportunities does this Grand Challenge offer now?

- Repair of equipment, particularly in remote locations
- Preparation of personalized food or medicines
- Diagnostic ‘factories’ to allow decision making (much miniaturized analytical equipment and diagnostics is often engineered from a lab concept)
- Just-in-time production of hazardous or short shelf-life materials with no inventory from stable inputs
- Formulation of products to avoid cold chain pharmaceutical distribution and better availability of drug products to the global population
- How can we achieve better compliance of patients in taking their medication, reducing wasted materials and reducing the cost of treatment for payers

What has already been done to address this challenge in the past and currently?

- 3-D printing has played a significant role and continues to grow
- Lab on a chip concepts and their translation to pragmatic diagnostics
- Intensified chemical processes using micro or milli-reactors
- Armed forces deployment and disaster recovery have some aspects of bespoke engineering, e.g., water purification
- Drug in a Bug approach
- Investment in continuous manufacturing in Pharmaceuticals is currently being addressed

What might be needed in the future?

See 1) and 2) for the sorts of applications that might need to be addressed. One aspect not addressed above might be manufacturing from simple feedstocks that can be readily
sourced where bespoke engineering is deployed. A good regulatory framework, particularly if bespoke engineering were deployed for food or medicine.

How does this Challenge fit in the current UK and global context?

It fits in the global context in that population centres are becoming more numerous and disperse. The consequence of this is that supply chains become more extended and difficult to support. Bespoke engineering should allow supply chain agility in response to population changes, but also in response to natural disasters or in war zones, where manufacturing can be implemented quickly in order to support displaced populations or armed forces. The pharmaceutical industry is changing with fewer blockbusters and more niche products. The concept of Stratified medicines is taking hold which again addresses smaller patient populations. The need for new manufacturing infrastructure /new technologies for advanced supply chains .This is an opportunity for the UK to provide technologies and supply chains with a global impact

How adaptable is it to the future?

This particular area is truly aimed at the future, so it is completely adaptable.

What can EPSRC do to address the challenge?

It is potentially an area with a huge scope, but also a potentially global impact. I think EPSRC might need to better flesh out the scope by understanding the top 3 bespoke engineering problems that if solved would make the greatest impact, and fund programs in these areas. Beyond this thought should be given to how to commercialise the ideas. And here EPSRC could be better linked to Catapults and TSB to ensure great concepts are fully applied.

Prof Richard Hague, Nottingham

How valid is the content within the Grand Challenge?

- Valid through not sufficiently focused/nebulous – need to articulate sub-challenges make this relevant to researchers
- Design side is missing – how do you design? Who does the design? are key questions to answer as part of this Grand Challenge
- Location of manufacturing is key
- Manufacturing at home is unlikely
- Process and location are key issues
- IPR infringement is also a key issue
- Use of the word personalised is best to be avoided in the context of the GC.

What opportunities does this Grand Challenge offer now?

- Additive manufacturing
- Questions are being asked already (to an extent)
- Materials (multi-functional) are key – how to manufacture a system and development of tools to do this is critical
- Notion of hub-based manufacturing
- Opportunities in identifying logistical issues for Grand Challenge e.g. Cambridge Institute for Manufacturing (IfM) work, including supply chains and processes
- Opportunity in design and configuration of appropriate materials

What can EPSRC do to help address this challenge?

- GC is valid as although research questions are being asked, there are currently no answers to them
- Fleshing out the GC is required e.g. what does bespoke engineering look like for specific sector such as Pharmaceuticals?
- Sub-challenge might be around how to deliver very low volume manufacturing for high-value products

**Dr Nicholas Medcalf, Loughborough**

How valid is the content within the Grand Challenge?

The content is valid and timely. It would be more strongly supported through inclusion of social considerations for the dynamic of uptake of any technology innovation.

What opportunities does this Grand Challenge offer now?

The inclusion of deferred completion of goods and management methods for inventory suitable for terminal customisation are aspects that can be considered. At present there is the nascent ‘Re-Distributed Manufacturing Network’ call (EPSRC/ESRC) and there may be some alignment between themes in the two initiatives.

What has already been done to address this challenge in the past and currently?

In the Healthcare sector (I am not so well qualified to comment on other sectors) there has been, and still is, considerable work in 3D bioprinting and milling (e.g. to supply dental implants) based upon patient data.

What might be needed in the future?

Healthcare again: To date tissue engineering has allowed the creation of single-format products. This work may be extended to provide customised bioactive products from viable biomass, thus extending the relatively expensive benefits of engineered tissue. However, to do this requires very good manufacturing controls to minimise waste and to assure known dosage of bioactive materials. It is thus a manufacturing challenge.

How does this Challenge fit in the current UK and global context?
From the UK point of view the important feature is satisfactory models of operation that can be used to satisfy standards and regulatory hurdles. The UK is well-placed to set the pace in healthcare applications because of the relatively harmonised structure of the NHS compared with private hospital chains. This gives a predictable User Requirement for receipt of goods and application in clinic. Successful work would provide a case study for emulation internationally but by that time UK providers would have established operations and a competitive lead.

How adaptable is it to the future?

Platforms of common technology can be identified by common product needs and some degree of future proofing can be assured by this approach e.g. bespoke implants with surface treatment can be applied to hips, knees, orthodontic applications and intra-medullary nails.

What can EPSRC do to help address this challenge?

Network formation bringing together systems engineers, data engineers, manufacturing specialists, quality assurance professionals and regulatory representatives will be the first step to flesh out specific opportunities. Support for this step is needed.

**Big Data for Engineering Futures**

**Prof Christopher James, Warwick**

How valid is the content within the GC?

The content is extremely valid and quite timely. We live in the age of data, it is in abundance, and it is available in many different forms – so much so that we hardly know to use it to its best advantage. We need a strategy now to deal with this challenge.

What opportunities does this Grand Challenge offer now?

The opportunities are in realising new “breeds” researchers, who are truly multidisciplinary – who bring together an understanding of (say) health and technology. E.g. creating very tech savvy clinicians who understand data, how it is visualised and where it comes from.

What has already been done to address this challenge in the past and currently?

There is an understanding in some areas more than others that data is key and that dissecting this there are valid areas where effort needs to be concentrated such as sensors, interpretation/visualisation, data security/quality assurance.

What might be needed in the future?

An understanding of what data is relevant – in health, for example, home electricity/water usage contributes to information on wellbeing, social interaction too. Furthermore it’s possible to measure complex “health” data in the home seamlessly now – so a mix of “low grade” physiological data with data from different channels, given the right interpretation can revolutionise wellness management (moving away from illness). I am sure this carries over to other areas too.
How does this Challenge fit in the current UK and global context?

It goes without saying that this area fits both UK and globally – its applicable in so many areas.

How adaptable is it to the future?

Data is the future. Where it comes from is becoming easier to obtain, cheaper, and with minimal effort – this can only increase. The data interpretation requirement will remain.

What can EPSRC do to address the challenge?

EPSRC can: i) help create and train true multi-disciplinarians who understand data and the issues surrounding its generation/processing challenges (and not be afraid to stray into areas not directly EPSRC – e.g., clinicians) ii) help grow disciplines that are cross-cutting in nature and move away from the small pockets of excellence culture we have in the UK – but rather grow strong networks where sharing/open information is the norm (e.g. biomedical engineering – the most fast growing area of engineering world-wide, yet in the UK whilst it is practiced in many places, it’s not connected and sharing/openness is not encouraged due to how funding is meted out); iii) help contribute to the curriculum development of new disciplines (even to graduate or postgraduate courses) to emphasise the skills required to work on big data.

**Prof Robert Mair, Cambridge**

How valid is the content within the GC?

The content is excellent. Additional key areas which are not mentioned are Resilience and Asset Management (both in the context of the UK’s physical infrastructure). Both depend on the revolution in the development and use of sensors for infrastructure, which must be robust, adaptable, low power, 24/7, and preferably deliver real time sensing (but not necessarily always real time, depending on the application).

What opportunities does this Grand Challenge offer now?

There are already huge opportunities for transforming the future of physical infrastructure through smarter information. Modern infrastructure and construction can benefit enormously from the innovative use of emerging technologies in sensor and data management. There are outstanding opportunities for these new technologies to make radical changes to the construction and management of infrastructure – leading to considerably enhanced efficiencies, economies, resilience and adaptability. New smart data capture and management will also enable improved understanding of cities and their demographic, socio-economic, land use and transport requirements.

The latest sensor technologies combined with advanced data acquisition and management can also transform industry through a whole-life approach to achieving sustainability in construction and infrastructure in an integrated way - design and commissioning, the construction process, exploitation and use, and eventual de-commissioning.

What has already been done to address this challenge in the past and currently?
There has been a revolution in sensor technologies applicable to physical infrastructure in the past few years, especially in the application of fibre optics, wireless sensors and computer vision. The Cambridge Centre for Smart Infrastructure and Construction (CSIC), funded by EPSRC/TSB and industry, has made substantial advances in pushing forward new frontiers of technology: in the past three years there have been over 40 collaborative projects with industry (with around 40 active industry partners), involving around 50 field demonstrations of fibre optics, wireless sensors and computer vision for a wide variety of infrastructure and new construction.

What might be needed in the future?

The engineering, management, maintenance and upgrading of infrastructure requires fresh thinking to minimise use of materials, energy and labour whilst still ensuring resilience. Future requirements include further development of fibre optic systems, as well as low power MEMS-based sensors combined with energy harvesting devices so that batteries are no longer required. Energy harvesting can be vibration-based, wind-based (natural wind or associated with trains) or solar-based. Future monitoring systems will undoubtedly comprise Wireless Sensor Networks (WSN) as part of the ‘internet of things’ and will be designed around the capabilities of autonomous nodes. Computer vision will be advanced to a very high level, enabling changes and defects in infrastructure to be identified. The Big Data from such systems of sensors and computer vision will be invaluable for assessing Resilience of physical infrastructure and for undertaking more rational and better informed Asset Management, thereby providing much greater confidence in prioritisation and delivering better value.

How does this Challenge fit in the current UK and global context?

High quality physical infrastructure (such as tunnels, bridges, roads, railways, buildings and utilities) is essential for supporting economic growth and productivity. It attracts globally-mobile businesses and promotes social well-being. Modern construction and existing infrastructure (some of it very old in the UK) must be robust, resilient and adaptable to changing patterns – particularly natural disasters and climate change. It also needs to be optimised in terms of efficiency, cost, low carbon footprint and service quality. A step-change in achieving robustness, resilience and adaptability will be through innovative applications of sensor technologies, data capture and data management – all associated with Big Data.

Acquisition and interpretation of Big data in the context of infrastructure will require civil engineers, sensor experts, electrical engineers, material engineers, and imaging experts. Data processing and management will require computer scientist and machine learning experts. Users will be owners and operators of infrastructure, many of which will be government agencies, and also social scientists.

How adaptable is it to the future?

Advanced sensor technologies, computer vision, data capture and data management are highly adaptable to the future.

What can EPSRC do to address the challenge?
Further support for fundamental research in the science and engineering of new sensor technologies, and their application to new understanding of infrastructure behaviour (particularly in structural and geotechnical engineering) would be invaluable to advance this rapidly advancing and important area.

**UCL, Various Contributors**

We’ve purposefully provided responses on a ‘per discipline’ basis, to provide an audit trail for each area of comment. On a more holistic basis, however, there is an increasing emphasis on the role that systems thinking/engineering can and needs to play in approaching and resolving so-called ‘wicked problems’ that embrace multiple disciplines. Such problems generally lead to a need to compile and handle Big Data sets.

How valid is the content within the GC?

**Department of Civil, Environment & Geomatics Engineering**

- The content is valid, particularly given the rapid developments of sensors and telecommunication which generate tremendous volumes and varieties of big data that will enable us to discover new ways of engineering – “digital engineering” that transcends traditional disciplinary research. However the challenge largely represents top down processes which aim to link public, administrative and structured data sets to the benefit of professionals, practitioners and policy makers. The challenge underrepresents the application of big data analytics for unstructured data sources such as social media and the role of crowdsourcing using smart technology to produce new data – a bottom up approach. In this respect the challenge underplays the role of the public as data providers. There is also a challenge in how algorithms can be developed to cope with large quantities of qualitative data that occur in social media. The challenge also needs to consider how the public will access this data to make informed decisions about how they behave. In this respect there needs to be a stronger public engagement strategy and a greater understanding of the ways in which big data can influence behaviour change. Big data is likely to provide data on outcomes but not on why these outcomes occurred.

- The public engagement strategy is also central to the Challenge because Big data can also feel like Big Brother to the public. For example there are already public concerns over the use of store card data to target marketing by business and the market value of health records to the insurance and medical industries.

**Department of Energy and Resources**

- Very important, in the mining, energy and natural resources fields, technology is developing at a rapid pace. In this environment, care must be taken to ensure big data considers health and safety, risk and ethics factors. For research, researchers and end users.

**Department of Computer Science and Machine Learning**
The overall picture is compelling to someone who is familiar with some of the issues, but might come across as a bit vague in terms of the actual research that needs to be undertaken. The issues with big data are perhaps in four main areas:

a. Systems for managing / accessing / manipulating the data
b. Extracting relevant information from large data sources
c. Learning from noisy data the patterns that are critical for the application
d. Learning through interaction with users

Faculty of Built Environment

The term 'Big Data' perhaps misses the point of the challenge – perhaps Linked Data is more of a grand challenge – joining the systems up ultimately creates Big Data but it is the joining and making sense of data that is the true challenge.

The content is valid in general, more emphasis should be put in particular on interoperability of different data streams and platforms.

Department of Chemical Engineering

Big data has a key role to play in research addressing the grand challenges facing governments, decision-makers and societies today. It is a cross-cutting theme. However, caution must also be shown. Issues not raised in the brief include:

- Subjectivity of outcomes
- Big data requires “big judgement”
- Context will still be key
- Fundamental research at the micro-level is still required

The content could also include 'manufacturing', as big data handling could be used to innovate manufacturing processes. The data in question would be physical or chemical in origin, and therefore will allow Chemical Engineering to contribute substantially, via the application of modern statistical mechanics approaches.

Molecular and multi-scale simulations are key to materials discovery, and chemical process and product analysis over practically relevant time and length scales. Transport phenomena, chemical kinetics, incorporating "heterogeneity" on multiple length scales in real processes, process systems analysis and control – simulations that incorporate all of these are essential to guide chemical process analysis and design, and to deal with their inherent complexity. The "grand challenge" here is to bridge the enormous range of length scales (sub-nanometer to multiple meters, or more) and time scales (picoseconds to years). We need improved scale-bridging
algorithms and methods to deal with the vast amounts of data generated from these simulations, and to reveal the essence contained therein.

Department of Mechanical Engineering

• The report “Big Data for Engineering Future” is a concise description of the Big Data issues, which serves as a good starting point for discussion. Some engineering examples and quantitative information would be useful to explain the challenges.

What opportunities does this Grand Challenge offer now?

Department of Civil, Environment & Geomatics Engineering

• To gain insight of engineering performance, which will in turn help us improve design, plan, and pro-action for industries and policies;
• To gain insight of user behaviours, which will in turn make positive change on individual and collective impacts to environment and facilities.
• To provide new software platforms to integrate disparate datasets and enhance the value of existing data. If this is achieved it offers an opportunity to evaluate policy in new ways. For example, if we can link travel and health data we might be able to understand whether people who switch from using cars to walking or cycling become healthier or were healthy already and how this has led to reduced health service use. At an aggregate level we could understand whether cities which have such policies to create modal shift have achieved better health for their citizens and reduced health care costs. Furthermore, we might understand whether this has been achieved without creating more injuries among vulnerable road users.

Department of Energy and Resources

• Big Data offers solutions and optimisations in UCL Australia’s areas of interest – the energy, mining and natural resources areas.

Department of Computer Science and Machine Learning

• Currently the grand challenge is quite open ended so many opportunities are open.

Faculty of Built Environment

• The challenge is timely, the technology is arguably in place but the processes and techniques are far from joined up. Big Data has arguably so far been a buzz word for a number of calls and awards that simply add to current silo style approaches.
• The challenge offers a big opportunity in creating processes that facilitate data interoperability. At the current state, the technology exists but we are far from attaining easy operations between different platforms and softwares that create, process and make sense of data.
Department of Chemical Engineering

- Engineering systems research requires big data, particularly when “non-technical” operands are coming into effect, such as human interactions and natural environment. Grand challenges of climate change (mitigation and adaptation), healthcare, resource management and energy security are ideally placed to benefit from big data analysis. Retail and manufacturing sectors are already using this approach.

Department of Mechanical Engineering

- By making Big Data a Grand Challenge, we can pool resources (including funding and expertise) together to solve generic problems facing engineering of the 21st century, many of which are data-rich.

What has already been done to address this challenge in the past and currently?

Department of Civil, Environment & Geomatics Engineering

- ESRC have big data initiatives (their original plan was 3 waves, to date two waves have been granted) – the 1st concerns administrative data, and the 2nd is on business data. These two waves are more focused on data collection and for business use (for social science and economics), not on cutting-edge research or broad engineering issues.

- EPSRC have several themes related to big data, such as ICT, Digital economy, health,..., but the emphasis is not on the data itself and the tools to integrate, analyse and visualise the data. A good example of Healthcare use is the SAIL database -The Secure Anonymised Information Linkage Databank (Swansea) – contact Professor Ronan Lyons.

- Open data has been a long-discussed topic, which improves the accessibility to government data (such as aggregated data in TfL or NHS), but due to privacy issues, the access to personal data (such as mobile phone data) is not possible at all.

Department of Energy and Resources

- Computer science, defence and software systems industries have been aware of the power of big data for some time. FMCG and now manufacturing and, in UCL Australia’s situation, global resource companies are starting to develop capabilities, but currently lag.

Department of Computer Science and Machine Learning

- There is support for big data in the biomedical domain and incipient calls from EPSRC. There is support for many facets of this type of research, e.g. sensors, machine learning, etc.

Faculty of Built Environment

- Smart cities and other smart initiatives all use big data. There is also work on linking data bases of buildings to their energy usage via the use of smart meters.
Department of Chemical Engineering

• Systems research is not new. Crowd-sourcing, data-mining, epidemiology, etc., used as techniques in gathering and analysing data with human interfaces. Open source software development (Linux system) and open innovation recognise the importance of extensive collaboration utilising the power of the Internet.

Department of Mechanical Engineering

• In the field of computational engineering using high-end computing (HEC), Big Data has been an increasingly challenging issue, as the computing power and size of datasets involved have experienced exponential growth in the past few decades. This has affected the ways that software is written and data analysis is conducted. So far, efforts to tackle the Big Data Grand Challenge have been from individuals. There has been no community-wide effort. In experimental research, datasets are becoming bigger and bigger, but I am not sure how much the experimentalists have done to tackle Big Data.

What might be needed in the future?

Department of Civil, Environment & Geomatics Engineering

• Understanding the data quality of existing datasets and how new technologies will improve upon the data so that old and new can be integrated for a sustainable future.

• Multi-disciplinary collaboration (computer science, engineers, social science) and interactions between academics, industries and the public

• New theories, methods and tools to deal with data in space and time in an integrated way, with the possibility that data might be irregularly-structured;

• New ways of thinking in terms of sampling and statistics given the big data make it possible to sample at much greater levels of discretisation

• Greater legal understanding of levels of ownership of and access to data

Department of Energy and Resources

• In addition to the obvious needs for data security, privacy and understanding risk, big data will need significant investment in skills, and both computing and data transfer power. Strong protocols to ensure that big data sharing happens within a sterile environment are also required.

• Understanding carefully the capacities, limitations, risks and impacts of a world in which the following become seamless, increasingly automated and with less predictable outcomes:

  o Self-diagnosis
  o Just-in-time
  o Real time decision making
- Advanced automation
- Social licence maintenance
- Virtual environments
- Nano-level hardware
- Material science

Department of Computer Science and Machine Learning

- An area of real weakness in the academic community is the inability to address data in a significant way – this is what large companies like Google, Amazon etc are able to do, but it requires traffic that university researchers typically do not have access to. Perhaps there is a need to fund a research facility that could help to generate traffic that would be accessible more widely for academic research.

Faculty of Built Environment

- A possible legal framework to ensure data interoperability across professions.
- Clarification of level of detail, level of access as well as data ownership.

Department of Chemical Engineering

- Policies related to privacy, security, intellectual property, and even liability, will need to be addressed. Protocols and guidelines on how to collect and store such data. Open collaboration and flexible business models. Skills shortages will need to be addressed.

Department of Mechanical Engineering

- Community-wide efforts and interdisciplinary approaches.

How does this Challenge fit in the current UK and global context?

Department of Civil, Environment & Geomatics Engineering

- Fits well in terms of global issues such as understanding economic markets, transport, climate change, health, cyber security etc.
- Big data is a priority research area in UK and pretty hot at global level – much of the activity is still talk with only a few groups having a clear picture and lead.

Department of Energy and Resources

- Big data has the potential to continue to push into new areas of society and, where used wisely, bring societal benefits.

Department of Computer Science and Machine Learning

- Very well in terms of the growth in data science and the industrial demand for this type of skill set.
Faculty of Built Environment

- The context is global with trials to be carried out at a UK scale to enhance UK services, competitiveness and knowledge base.

- With advancement in data modelling, UK is in a good position to lead in this area.

Department of Chemical Engineering

- The UK government, in line with others, is struggling with a trilemma of energy security, climate change and economic growth. The National Health System is also coming under increasing pressure. Resource security (food, water, metals and minerals), urban planning, global trade, all require a systems approach and big data.

Department of Mechanical Engineering

- In the USA, Big Data is considered as the fourth paradigm for science and technology development (Department of Energy report, 2013) following theory, experiment and large-scale computation. There are signs of significant research and funding in the area in the coming years. The UK is facing similar challenges, and with its strong research base, can play a significant role in the field.

How adaptable is it to the future?

Department of Civil, Environment & Geomatics Engineering

- The Challenge is one of the most important ways to shape the future, to science, industry and citizens. The Challenge needs to have a horizon scanning ‘future scoping’ component or think tank that will lead to a Big Data Roadmap capable of societal scrutiny.

Department of Energy and Resources

- Readily adaptable and flexible.

Department of Computer Science and Machine Learning

- This would appear very adaptable since it cuts across so many application areas and can influence so many different demands: control, information access, safety, etc.

Faculty of Built Environment

- Any focus on linked data is by nature adaptable – thus the grand challenge to solve the futures data challenges.

Department of Chemical Engineering

- Data sets will continue to grow in size as use of mobile devices, remote sensing, wireless networks, etc., continue to grow. Everything is part of a system, at one scale or another.

Department of Mechanical Engineering
• Big data is more about the future than the present, and its importance increases with time. This Grand Challenge will prepare us for the future and support many key disciplines in engineering (and science).

What can EPSRC do to address the challenge?

Department of Civil, Environment & Geomatics Engineering

• Acknowledge the link between top down and bottom up data
• Commission research into:
  o Public engagement in the Big data agenda, particularly how the public can use and contribute to Big data, for example by exploiting citizen science.
  o Algorithms and new statistical thinking to cope with unstructured data sources
  o Understanding what data linkage can and cannot achieve – how can we understand the ‘why’
  o How it can be used to evaluate policy and planning
  o Fellowship programme to champion start in big data domain – particularly targeting new and middle level academics
  o Several platform grants to support a few focused big data applications – transport (perhaps in collaboration with Horizon 2020 where there is already a strong emphasis), crime, health, planning and policy
  o DTCs (data scientists with a portfolio of relevant skills including interdisciplinary working are very much needed)

Department of Energy and Resources

• Engage externally, with other research institutions, government and industry to understand risks and opportunities.

Department of Computer Science and Machine Learning

• Some targeted funding could be very helpful as would assistance in helping to define the key research questions in what is often a quite ill-defined concept.

Faculty of Built Environment

• Arguably a number of platform style grants, along with a series of PhD places – made cross discipline / cross research council.
• Providing research grants to feed into what industry is already doing.

Department of Chemical Engineering

• Link with other RCs to recognise the need to support multidisciplinary research, whilst still recognising that fundamental research to explain micro-scale behaviour is required.
Department of Mechanical Engineering

Making Big Data a Grand Challenge is a good first step. Funding for various initiatives is required to meet the grand challenge.

**Suprastructures**

**Prof Jim Hall, Oxford**

How valid is the content within the Grand Challenge?

Broadly speaking I agree with the direction of the Suprastructures challenge. There are two areas with potential for transformative contributions (grand challenges if you like): (i) harnessing ICT in ‘smart’ infrastructure i.e. riding today’s Kondratiev wave (ii) mastering the system i.e. synthesising disparate assets and networks in order to access new efficiencies and manage risks. The two are of course linked.

Whilst setting out some very relevant issues, the document does is not explicit about what the research challenge is supposed to be. That needs to be sharpened.

What opportunities does this Grand Challenge offer now?

The challenge is very timely. Infrastructure is high on the UK government’s agenda and the UK is expecting to invest very large sums in infrastructure over the coming decade and beyond. Even more is being spent elsewhere in the world, especially in emerging economies. The UK has the potential to propose a distinctive offering.

And beyond that economic and societal relevance, there are some serious intellectual challenges. Again I would single out (i) the ICT/sensing/control engineering/big data challenges, and (ii) the systems challenges, which encompass environmental hazards and links with the economy. The more I look into this, the more I understand about the huge gap between engineers’ understanding of physical systems and what economists can (and can’t) say about the link between this special form of capital and the economy.

What has already been done to address this challenge in the past and currently?

The research community is getting its act together, broadly around the ITRC/iBuild/ICIF/ARCC cluster. I’m less familiar with the ICT/sensing/control engineering/big data area.

What might be needed in the future?

I think we now need to specify, more clearly than in the Suprastructures document, what the distinctive UK science/engineering offering could be. There is a growing community, partly thanks to EPSRC directed activities (ARCC, iBuild, ICIF), partly self-organising (ITRC), and lots of strength in the component disciplines (water, transport, waste, and especially energy and ICT). We (the research community) need to be pushed to articulate the grand challenge more effectively. I don’t think we’ve stepped up to that yet.

How does this Challenge fit in the current UK and global context?

See above
How adaptable is it to the future?

i.e. will it go away, is it future-proof? It is very hard to see how it could go away, though it is certainly possible to see how the UK could become marginalised.

What can EPSRC do to help address this challenge?

Work with the community to articulate the challenge better. Sustain support to build capacity. Work out how to cross boundaries e.g. into the natural environment (essential for understanding natural hazards and natural resources) and the economy.

Prof Simon Pollard, Cranfield

How valid is the content within the GC?

The challenge is well crafted. A key item to consider is bridging the gap between the research ambition and where many of the utilities are, right now. To keep industry closely engaged, there will be a need for some lower TRL work here, accessing and working with incomplete data sets, limited in-house capabilities, and incomplete or ill-defined thinking around the concept of ‘superstructures’. It is critical for our credibility that we take the various industrial sectors with us, to have deep impact, so we should be wary (at least in my view) of projects that tend too far towards the esoteric on such a practical set of issues. The transition towards the ambitions set out in the challenge will be exploratory and messy and we need, therefore, to fund activities and consortia that are prepared to tackle these issues ‘full-on’, rather than design overly elegant but impractical solutions. There are considerable challenges around design, data provenance, the cost of importing redundancy (resilience) back into linked systems. I do believe the term resilience is well-defined. See here:

What opportunities does this Grand Challenge offer now?

Following on from above, there are probably opportunities right across the EPSRC delivery vehicle from fellowships out to programme grants. Has someone mapped out the full set of funding on this that is active at present, and funded within the last 5 years, so we don’t duplicate? There has been an enormous amount of work done, right back to EPSRC SUE I etc. Building on the general statements in the overview, what is absolutely brand new, not funded that we might direct folk towards?

What has already been done to address this challenge in the past and currently?

SUE I, II, IRTC, etc. I imagine this is well known to EPSRC. Also the various strands of business/sector work via HMT Infrastructure and its committees.

What might be needed in the future?

More research using the authentic data that infrastructure stakeholders have, perhaps. Drawing in NERC re. the environmental/strategic planning focus, GIS etc. Architects, designers, citizens – creative and innovative exchanges that give alternative angles on these challenges. What is it/would it be like to live in one of these new cities? Agree with comment
about the industrial strategies required to support the superstructures. Financing these cities and structures?

How does this Challenge fit in the current UK and global context?

One of a number of international programmes looking at the same. What is the specific UK USP/take/national capability on this agenda?

How adaptable is it to the future?

Addressed in other sections

What can EPSRC do to address the challenge?

Addressed in other sections

**Prof Chris Rogers, Birmingham**

How valid is the content within the GC?

The challenge is completely valid although slightly superficial – core ideas are there need developing. The academic community in this area is well aligned and working together in many aspects already and if a capital bid is successful could address the complex challenge presented.

What opportunities does this Grand Challenge offer now?

Area of research is working up towards large capital bid so research facing this challenge area could complement and fill the research activates of any successful capital bid in the infrastructure area. It has enormous potential.

What has already been done to address this challenge in the past and currently?

Many large programmes currently being funded: Liveable Cities, Infrastructure Systems, EPSRC/ESRC business models, Assessing the underworld, Foresight Future of cities, Smart Infrastructure, Future cities Catapult

What might be needed in the future?

A successful capital bid would lay foundations for a network; as would linking many of the currently funded large projects. The challenge could be framed as an ambitious research programme linked to a UK centre for infrastructure.

How does this Challenge fit in the current UK and global context?

Very well indeed –we are showing a world lead in much of this.

How adaptable is it to the future?

Researchers in this area is already taking a “far-future” view of this challenge

What can EPSRC do to address the challenge?
Provide funding to complement a national effort to set up a UK Centre for Infrastructure and Cities. Build on the intellectual capacity which has been built up through various initiatives (e.g. SUE) to deliver three pillar benefits.