National Infrastructure Commission: interim National Infrastructure Assessment - call for evidence

Response to the National Infrastructure Commission, 12 January 2018

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The Royal Academy of Engineering welcomes this opportunity to submit evidence to the National Infrastructure Commission (NIC). As the UK's national academy for engineering, we bring together the most successful and talented engineers from across the engineering sectors for a shared purpose: to advance and promote excellence in engineering.

Through its Fellowship, the Academy has access to highly qualified individuals in infrastructure, systems engineering, construction, digital systems, civil and structural engineering, energy, transport, flooding and water supply. Their expertise spans research, policy making, regulation and practice including the management of major projects. This response is based on the views of Fellows and on policy studies that the Academy has undertaken.

Introduction

1. Common threads that run through the NIC's consultation document as well as the Academy's response are:
   - the need for both new and improved infrastructure and for new and existing infrastructure to rapidly adapt to increasing demand
   - identifying key uncertainties related to a changing natural environment as well as fast-paced developments in new technologies, delivery and service models
   - growing interdependencies between infrastructure systems.
2. As an example of growing interdependence, the transition to a low carbon energy system over the next thirty years will have major implications for the built environment and digital infrastructure, as well as the infrastructure that transmits and distributes energy. An economy based on the internet of things will be much more able to deliver energy as a series of services rather than a commodity, with potential for greater customer satisfaction and lower costs, but it could also expose the nation's critical energy system to more systemic accidental or malicious failures, making security a top priority for the digital infrastructure.
3. The strong possibility of connected, autonomous vehicles (CAVs) may well change the nature of transport and the energy infrastructure required to support it. Mobility is currently dominated by automotive solutions, such as the car. However, the car is a very under-utilised asset; being in use for just 4% of the time on average[1]. If CAVs can deliver an intensity of use more like 15%, that would transform personal transport and radically change the design and operating requirements for vehicles and the energy system.
4. Changes in the cost of personal transport and regional differences between the availability of different modes of transport will impact on the attractiveness of different locations as places to live and work. The impact of decarbonisation on housing and the quality of local energy strategies will also impact on this. Decisions on vehicle charging, hydrogen for transport or heating and whether buildings will be heated by electricity, district heating or some form of zero carbon gas, will have a major impact on the system of local pipes and wires, including the use of land and street furniture. In short:
   - the energy transition will require major investments across all elements if the energy system, most likely under time pressure
   - transport and information technology infrastructures will interact strongly with the energy system

[1] Spaced Out: Perspectives on Parking Policy, RAC Foundation, 2012

- there will be highly regionally specific characteristics to infrastructure transitions rather than a single national solution.

5. The key trends highlighted and briefly illustrated above point to an urgent need for resilient, learning organisations and user communities that inform a much greater capability and application of systems engineering[2] in how infrastructure decisions are made and how the interaction of systems is managed. The importance of infrastructure decisions, the need to make these under significant levels of uncertainty, and the need to avoid 'systems accidents', as the NIC have defined them, requires fostering the right learning and decision-making environment. Cross-domain collaboration that feeds into an effective systems engineering function is an urgent requirement and processes will need to be designed to transgress traditional silos, disciplines and domains. This is a significant challenge and thought needs to be given to how best to bring together decision-makers and stakeholders in infrastructure with practitioners in infrastructure design, delivery, operation and maintenance and thought-leaders in research and new technological capabilities. The challenge is to continuously, routinely and transparently engage stakeholders, users and beneficiaries of infrastructure in the decision-making process. Through the creation of shared understanding, decision-making can be improved and user behaviour become more collaborative and adaptable.

6. Thought and rigour need to be brought to bear on what processes of organisational learning and decision-making are required and how these feed into systems engineering functions that promote and ensure resilience and adaption to uncertain infrastructure futures. This will ultimately need to ensure resilient, learning organisations, full utilisation of the opportunities presented by 'smart' infrastructure, new modelling capabilities and informatics, and an open approach to engaging stakeholders in defining both the needs or purposes being met by infrastructure and how this is achieved.

7. The Academy is keen to work with government on the challenges raised in this response, including to ensure that the necessary cross-domain collaboration takes place. By working together with the stakeholders described above and across the engineering, science and commercial base the UK can not only realise the profound benefits from modern infrastructure but also develop comparative advantage in important areas of infrastructure systems delivery, thereby turning infrastructure challenges into opportunities for the economy and international trade.

1) How does the UK maximise the opportunities for its infrastructure, and mitigate the risks, from Brexit?

Skills and infrastructure delivery

8. UK infrastructure businesses employ many thousands of EU citizens and rely on the ability to bring in specialists. The construction sector also depends on a transitory EU workforce. Skilled labour from other EU countries makes up 9% of the UK construction workforce (making it the third most reliant sector after hospitality and manufacturing)[3].

9. Making every effort to increase the domestic pipeline of engineers in the UK must clearly be part of the response to leaving the EU. However, the pace of technology development combined with the length of time it takes to fully train qualified engineers means that it is impossible to fill all engineering skills gaps or shortages in this way. Delivery of major infrastructure projects often depends on the availability of large numbers of people with specific skills for a fixed period and, at present, the EU is an important source of engineers deployed on UK projects. Additionally, in some sectors, such as electricity distribution, the movement of engineers quickly across EU borders to supplement local staff is critical to maintaining and repairing the UK's infrastructure in times of emergency. The UK and individual companies need to pay close attention to

[2] For an example that explores a 'one system' approach to energy and potential options for a 'systems architect' see Transforming the electricity system, Institution for Engineering and Technology, 2014.
[3] Brexit: impact across policy areas, House of Commons Library, 2016, p375

where peaks and troughs in the demand for labour will occur and as much flexibility as possible needs to be maintained for meeting demand, including making inter-company movement as frictionless as possible

10. There can be no doubt that the country needs skilled workers to build, maintain and operate its economic infrastructure. The 2017 National Infrastructure Pipeline (NIP) sets out a projection of public and private infrastructure investment levels according to which total investment over the next 10 years will be around £600 billion[4]. Delivery of the programmes and projects in the NIP will need innovative and productive techniques requiring new and different mixes of skills and experience. Uncertainty about the status of EU workers in the UK is likely to exacerbate recruitment difficulties, resulting in increasing costs where demand for labour outstrips supply and the risk of project delays[5].

11. In the first instance, a greater understanding of the vulnerabilities is needed. A comprehensive audit of current dependencies on the EU, including a review of major infrastructure projects that are underway or planned to understand vulnerabilities to changes in access to European funding, labour, collaboration, and research and development (R&D) should be undertaken. Such an audit can also provide the basis of a framework for evaluating the success of actions taken to maximise the opportunities and mitigate the risks associated with leaving the EU.

Standards

12. Through the application of standards, the EU has developed commonality of technical requirements across manufacturing, infrastructure and environmental sectors. Standards are a common means of ensuring legal compliance (although not necessarily the only means of compliance) and an important requirement for access to the single market across 33 countries through the European Standardization Organizations (ESOs) – CEN, the CENELEC and ETSI. The UK is represented in these organisations by the British Standards Institution (BSI).

13. Standards have multiple benefits; they contribute to GDP growth, increase productivity[6], provide confidence and a common trading language, lower production costs, reduce barriers to trade, and encourage economies of scale[7]. Standards can act as a catalyst for innovation and enable compatibility and interoperability.

14. When CEN or CENELEC adopts a European standard, all their national member standards bodies must adopt that standard identically and withdraw any national standard that conflicts with it. Continued membership of the ESOs would commit the UK to maintain this 'single standard model'.

15. Though the UK has the option to develop its own standards, this entails a high risk of divergence from European practice, bringing complexity and added costs for the UK and potentially damaging the country's reputation as a global trading, research and innovation partner. Indeed, non-EU countries are increasingly using CEN standards as the basis for their own, meaning that it would be difficult for independently developed British standards to influence world markets.

16. Given the UK's level of current engagement and expertise, the UK's continued membership of CEN and CENELEC would be desirable for all parties. On the basis that CEN and CENELEC are not agencies of the EU and that their current membership is

[4] Analysis of the National Infrastructure and Construction Pipeline, Infrastructure and Projects Authority, 2017
[5] Infrastructure 2050, Balfour Beatty, 2016
[6] The Economic Contribution of Standards to the UK Economy, Centre for Economics and Business Research, 2015, p90
[7] The Economics of Standardization, GMP Swann, 2000

broader than the EU, the BSI's expectation is to remain a full member, nevertheless, this is not a foregone conclusion since, also according to the BSI[8]:

- A technical amendment to the statutes of CEN and CENELEC might be required.
- UK government would need to continue a regulatory approach that supports the single standard model with its commitment to the adoption of internationally agreed standards and that maintains the rigour of the standards regime in the UK.
- UK government needs to ensure that it does not recognize national standards from other countries as a means of legal compliance in the UK.

17. Outside the standards organisations, the UK could still choose to adhere to European standards for goods and services produced in the UK for export and trade as now, but it would have lost the ability to protect UK interests through participation in setting standards.

Eurocodes

18. There are 10 Eurocodes with a total of 58 parts aimed at harmonising infrastructure and building design that were developed by CEN with the support of the European Commission and came into force in 2010. While they were a European Commission initiative, as they were drawn up and continue to be monitored by CEN, they apply across both EU and non-EU CEN parties[9]. Eurocodes introduced common technical rules, for example, around fire resistance, building stability and construction products. They replaced existing individual member states' codes, although there are many similarities between Eurocode rules and methodologies and the preceding British standards.

19. In common with other CEN standards, as they can, and do, apply to countries outside of the EU/EEA, their continued adoption in the UK would be the best approach. It would take considerable time and expense for the UK to develop its own replacement codes. As with other CEN standards, continuing use of Eurocodes would allow the significant number of UK built environment companies operating in the EU to adhere to one common set of rules rather than face the expense of complying with two.

20. CEN has recently embarked on the development of the second generation of EN Eurocodes, for which it has received its largest ever single standardisation grant from the European Commission. This process is currently under the leadership of a UK chair and UK secretariat. It would be damaging to the UK interest to lose such influence over a suite of standards used by engineers around the world, both within the EU and in many countries outside it.

State aid

21. EU state aid rules aim to ensure equality in competition by restricting government financial support or material backing to companies. The European Commission must give prior approval: if state aid is given without clearance, it will be deemed to be unlawful (though there are exceptions where approval is presumed[10]). If the UK leaves the EU and does not join the EEA[11], EU state aid rules will cease to apply. The potential removal or diminishing applicability of state aid rules might allow development of an invigorated domestic industrial strategy with more emphasis on hi-tech innovation in engineering and manufacturing and the forging of new trade partnerships. The UK could use the opportunity to develop its own policies on supporting strategically or economically important technologies or sectors. This could enable the UK government

[8] What Brexit means for industry standards, BSI, 2017
[9] See, for example: Adoption of Eurocodes in the Balkan Region, JRC Scientific and Policy Reports, 2014.
[10] State Aid: General Block Exemption Guidance, Department for Business Innovation and Skills, 2014
[11] State aid rules apply to EEA member states in broadly the same way as they do in the EU. Switzerland has a series of sectoral bilateral agreements with the EU that include limits on state aid, but there are no blanket restrictions. See for example: Brexit: implications for state aid rules, Oxera, 2016.

to provide support to large-scale infrastructure, such as energy generation, either through direct capital funding or tax incentives.

22. However, even outside the EEA, the UK would remain bound by World Trade Organization (WTO) rules relating to subsidies, which are based on similar, albeit narrower principles. These include its Agreement on Subsidies and Countervailing Measures, which governs government provision of financial support, for example, around subsides for renewable energy[12].

23. Under WTO regulations, there is no notification and approval process, and effectively, states enforce the rules. While being governed by such a system has the potential advantage for the UK that there would be fewer restrictions on the application of state aid, it would also mean a weakening of its ability to stop other nations engaging in practices detrimental to UK businesses.

24. As any changes to state aid following the UK's exit from the EU are likely to have far-reaching consequences to a wide range of UK businesses, it is important not only to the economy but in critical infrastructure sectors such as energy generation, that alteration to the rules should be examined in the context of their potential to support UK infrastructure as well as the industrial strategy.

Industrial strategy

25. With or without the EU referendum vote, the engineering community is strongly supportive of the government's decision to develop a new industrial strategy. An industrial strategy should be the primary vehicle for taking advantage of global opportunities during and beyond this period of transition. The Academy's response to the government's green paper on industrial strategy[13] set out the engineering professions view on the key properties and outcomes of a successful industrial strategy for the UK.

2) How might an expert national infrastructure design panel best add value and support good design in UK infrastructure? What other measures could support these aims?

26. The proposal for a national infrastructure design panel should be approached with caution since design panels themselves require extremely careful 'design' to ensure a positive impact and mitigate some of the potential pitfalls of this approach. At their best, design panels can achieve highly effective strategic input. However, at their worst, they can be mediocre 'tickbox' exercises that legitimise ill-conceived design and delivery.

27. Infrastructure design is primarily about utility in serving the original intended function. The key task is to maximise functionality across social, economic and environmental outcomes in the face of many, often complex constraints. Beyond this, there are some key principles that need to be 'designed in' and would, under the correct circumstances, constitute good design, for example:

    - The affordability, accessibility and inclusivity of infrastructure
    - The adaptability of infrastructure; most infrastructure assets are very long-lived - lasting for centuries, perhaps millennia, often in a highly altered form. They will typically be reconfigured and repurposed more than once during their life. While futures are uncertain and there is never a cost-effective solution that can be built to cope with any future scenario, infrastructure built today can either limit future options and introduce path dependencies or, if designed with flexibility toward the

[12] Brexit – the implications for the renewables market, Simmons and Simmons, 2016

[13] Engineering an economy that works for all: industrial strategy green paper response, Royal Academy of Engineering, 2017

future in mind, might provide adaptability and maintain performance long into the future.

Outside of these principles, the definition of 'good design' should remain open to allow the desired outcomes to be defined and met in innovative and creative ways.

28. However, given that, in contrast to many other branches of engineering, the scale of infrastructure projects means that prototyping is generally not realistic, design standards provide a basis against which the adequacy of designs can be verified prior to construction. This includes matters of safety, in service performance, durability and resilience. They also form a basis for contractual requirements between parties and enable lessons learned and new research findings to become adopted across a sometimes-fragmented industry. Therefore, chosen to suit the right context, design standards together with providing supporting guidance do play a key role in defining some of the essential requirements from infrastructure.

29. The terms of reference and statutory powers of the panel would need careful and considered specification from the outset. However, provided there is appropriate governance and structure and sufficiently broad representation across regional and transdisciplinary expertise there is the scope to provide value.

30. Guidance on what constitutes good design should be developed with care to recognise that design is a constantly developing discipline the value in which is often to achieve bespoke solutions to unique problem contexts, involving creativity and often innovation. It is important that any design panel and associated metrics for design quality do not stifle this creativity and innovation – much of which can often best be driven by making it a source of competitive advantage for those competing for infrastructure design and delivery. The danger is that any design panel that is established adopts a view of design that is static and defined by the prejudices and experience of those constituting the panel. Any guidance should be set out in a language that is accessible and understood across stakeholders, disciplines and scales of projects.

31. Finally, good design of UK infrastructure needs good engineering at its heart. If a national infrastructure design panel is established then we strongly advocate that its membership and remit place excellence in engineering at its core. While satisfying design standards is a pre-requisite for good designs, this alone it is not sufficient. Given the important interaction and relationship between design standards and achieving good design, it is recommended that any design panel includes expertise in the development and implementation of engineering design standards and the qualities of good standards within its membership.

3) How can the set of proposed metrics for infrastructure performance (set out in Annex A) be improved?

32. The principle of creating a transparent set of performance metrics for infrastructure is sound. The draft metrics significantly improve on those proposed in the 2014 National Infrastructure Plan. However, some observations and areas for potential improvements can be identified as follows.

Overall coverage and omissions

33. While the current set of indicators map reasonably well to the three pillars of sustainability (economy, society, environment), they do not include any reference to health, safety or wellbeing.

34. A recent review of international best practice in infrastructure performance metrics[14] recommends a balanced set of metrics reflecting system performance, user satisfaction

[14] Infrastructure performance indicators – a new approach based on the Sustainable Development Goals, Masterton, G.G.T., Findlay, T., Wright, M. and Smith, S. D., 2017

and wellbeing. The metrics proposed in the consultation include a category for quality of user experience, for which the data source is principally user satisfaction derived from survey data. This would address one of the previously missing dimensions. However, none of the metrics could be described as measures of wellbeing. Given that the consultation document notes that the NIC does not intend to replicate the work of other organisations, it may be that the NIC has concluded that the Office of National Statistics is the appropriate organisation to report on national wellbeing. However, infrastructure has a significant impact on physical and mental wellbeing, therefore it might be helpful to draw attention to a range of metrics reported by ONS, say, that could be reported by the NIC as metrics with which the NIC is also concerned and interested.

35. There is no direct reference in the metrics to the Sustainable Development Goals (SDGs). Masterton et al[15] suggest 45 tentative indicators intended to be consistent with the SDGs and other international metrics, to deal with system, user satisfaction and wellbeing facets, and to meet the criteria of being meaningful, outcome focused, objective and neutral while capturing multiple stakeholder perspectives. A comparison with the 48 bulleted metrics in Annex A has 18 direct matches, with a further one (a Natural Capital Asset Index, or equivalent) mentioned in the preamble as an intended addition. Wellbeing metrics account for 13 of the mismatches, and a further 6 are due to different user satisfaction metrics.

36. The NIC should consider the inclusion of a safety-focused metric. For example, other national and international sets of infrastructure performance metrics have fatalities due to road traffic accidents as a key metric, and the SDGs set the target of halving road deaths by 2020. Given that safety of users is surely key in every sector of infrastructure, it is arguable that user safety should be a category in its own right. It would be possible to construct suitable safety metrics for energy, waste, water flood risk and digital communications. However, road deaths have such a heavy toll and economic and social consequences that this, at least, should be considered as an added metric.

Lagging versus leading indicators

37. It is essential that the intended purpose and use of metrics is clear. The metrics as drafted are almost all 'lagging indicators' insofar as they report on past performance rather than providing confidence in future performance, particularly if circumstances and demands change. The 'resilience to large shocks' measure could serve as a 'leading indicator' and is supported, however the detail of this measure needs to be resolved. However, it is not just 'large shocks' that should be a concern. More gradual changes over time may place the greatest stress on the UK's infrastructure, such as demographic shifts, climate change and natural resource availability.

38. It is recommended that NIC split the indicators into two sets. A set of 'lagging indicators' that track past performance and a set of 'leading indicators' that give confidence in future performance and/or enable early identification of issues, so that they can be mitigated in advance of having an adverse impact on infrastructure users.

Infrastructure as a system-of-systems

39. While the consultation document recognises that infrastructure is a complex system-of-systems, the proposed metrics have been siloed into six separate infrastructure sectors, making cross-dependent metrics difficult to track. While there may be some convenience from sectoral divisions, this will not lend itself to measuring interdependent performance. For example, a failure in digital communications could

[15] Infrastructure performance indicators – a new approach based on the Sustainable Development Goals, Masterton, G.G.T., Findlay, T., Wright, M. and Smith, S. D., 2017

have a major impact on other sectors, deteriorating their performance metrics. Smart stress tests would have to be devised to assess the many interdependencies.

Design quality

40. The category 'Quality of User Experience' has the metric of 'Design quality' for each sector. Here we refer back to our response to Question 2. There are serious difficulties in defining this in a way that is meaningful, objective, neutral and representative of multiple stakeholders and of the specific contexts in which infrastructure is built. There are legitimate questions on whether user satisfaction should always be regarded as the necessary and sufficient metric for design quality.

4) Cost-benefit analysis too often focuses on producing too much detail about too few alternatives. What sort of tools would best ensure the full range of options are identified to inform the selection of future projects?

The limitations of current CBA

41. The Academy welcomes the recognition that Cost-Benefit Analysis (CBA) too often narrows the scope of considerations too early. Academy Fellows report instances where terms of reference for analyses have been too constrained, excluding options (often already examined) that would meet the same purpose.

42. CBA is also frequently misused. Schemes are typically accepted if the benefit/cost ratio (BCR) exceeds a current threshold. However, this only tells us that a scheme is potentially worth building and not whether it is the most appropriate solution to the problem. CBA can also often be used too late in the design process to justify schemes that have already been designed; for post hoc justification rather than identification of alternatives or enhancement of scheme design.

43. Large projects take an appreciable time to reach final commitment (placing of contracts). Needs may have changed[16], and alternatives become available. It would be good practice to carry out an updated CBA independently of the project team prior to final commitment, such as placing of construction contracts, taking account of all the latest projected needs and the alternatives then available. The independence of the project team is important; large projects gather a certain 'momentum' and associated mindset, thus CBA and alternatives should be conducted by an independent organisation.

44. The lifetimes of infrastructure pose a challenge in CBA. For example, most energy schemes have a limited life of about 35 to 50 years while tidal and hydro schemes have lives of over 100 years, however current CBA assessment takes almost no cognisance of this longer life. This was highlighted in a House of Commons Energy and Climate Change Committee report[17]. We recommend the government ensure that levelised cost of energy analysis reflects a fair appraisal of long term cost and power generation, which takes into account the full lifecycle of long-lived projects, such as marine energy projects. Additionally, in relation to renewable energy, the intermittency of some renewable energy sources also poses a challenge with different sources of energy having different levels of variability, predictability and match to patterns of demand. CBA in the energy sector needs to be adapted to take full account of such features.

45. CBA also omits benefits which only accrue from the consequences of a complete system; failing to value the benefits that flow from dependencies of other sectors, for example, the wider economic benefits of growth from investment in major trunk road schemes rather than just time saved on a particular journey or the impacts of loss of water on other sectors. Economic infrastructure need to be treated as big, complete systems and

[16] For example, Kielder dam, a major project, was approved in the 1960's on the basis of the heavy industry greatly expand its capacity (and hence its need for water) in the area. However, in the event, heavy industry declined rather than expanded leading to much criticism of the final project.

[17] A Severn Barrage?, House of Commons Energy and Climate Change Committee, 2013, para. 27-28

need to be planned and analysed as whole systems. Piecemeal approaches too often focus on each individual link within infrastructure systems in isolation, leading to a lack of economies of scale in system development.

46. While current evaluation techniques assume future reliable performance, they need to be much stronger at validating the realistic future cost of operation, maintenance and component replacement. CBA often focuses too heavily on reducing initial costs rather than taking a full view of the total costs across the life time of infrastructure projects. The constraints imposed by the emphasis on lowest initial costs can create sub-optimal solutions and increased costs over the life time of infrastructure. Furthermore, cost-benefit techniques do not recognise the value of infrastructure that is essentially enabling infrastructure, with limited or occasional use. This includes failure to value spare system capacity that will enable future maintenance or system reconfiguration without impacting on service levels.

47. Cost-benefit techniques do not support investment in other forms of enabling infrastructure that contribute to overall national performance but do not in themselves earn revenue in an economic sense. Skills training, defence provision, and social and welfare provision are all areas that support the wider economy and have their own infrastructure requirement but that are poorly evaluated in their contribution to the performance of the economy.

48. Furthermore, CBA has limited use where the consequence of a failure could be catastrophic but is highly random or extremely rare, for example in major flood defences.

49. Finally, it is also worth noting that, in contrast to other countries, the UK has a hesitant approach to infrastructure development. For example, only upgrading routes after they had already become congested, justified by CBA, has increased the total UK costs of major infrastructure upgrade, while starving isolated regions of connectivity, impairing their economic development. In contrast, the development of the US interstate highways system, the German autobahnen and the Irish motorways were all done as part of a national plan – which has had the effect of spreading wealth around the country and connecting isolated regions. It would be highly beneficial if the portion of infrastructure projects that are of national significance within the UK were placed within a strong national vision.

Beyond current CBA practices

50. While there is most certainly a balance to be struck between identifying many options and investing in option appraisal (with all the associated costs), there needs to be a broad approach with little initial constraint to start with in identifying possible solutions and early consultation to sieve out those that cannot proceed for valid reasons or need to be amended. There is a strong case for adopting a problem-based approach in which the problem is identified, the potential benefit to be gained by overcoming the problem assessed, the maximum project cost determined as that which achieves at least a given BCR, and solutions sought within that cost ceiling. Here the role of CBA would to determine the cost ceiling for a more problem-centred approach to considering a fuller range of alternatives that are feasible within that cost ceiling[18]. Within this approach, there must be sufficient attention to the upfront identification and agreement with interested parties on what the problem is. There needs to be early engagement with all those affected and then on-going dialogue to ensure all view points and impacts are understood before solutions are identified[19].

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[18] The successful Train Protection Warning System (TPWS) in use on Network Rail's Infrastructure was conceived and selected in this way.

[19] We recognise that there are risks associated with this approach around raising expectations, particularly for expensive options or raising early objections which put at risk any solution, particularly on legal grounds. Such risks need to be carefully managed.

51. A tool that values wider economic benefits in a consistent way would help direct investment that maximises benefits on a specific project. However, it is very difficult to reduce all costs and benefits from infrastructure schemes to economic measures and this should be avoided. Most organisations now deploy a balanced scorecard of some sort when evaluating past performance and future strategy, and this approach should apply for city, regional and national infrastructure. If this were done then it might be possible to consider cost-benefits across multiple government departments as well, and so deal with cross-boundary interdependencies[20].

52. While current CBA uses the costs and benefits of options and seeks to optimise the return on investment, other tools such as using carbon as a common currency or natural capital are receiving attention and need to be further developed to compare with traditional CBA. In the longer term, as they mature, government should consider moving to these new ways of analysis, particularly around valuing externalities.

53. Finally, with the aim of developing better approaches to infrastructure investment, the EPSRC and ESRC have, over recent years, made investments in two multi-university academic centres with the aim of exploring how to make UK infrastructure an attractive, global investment opportunity, each for around £3m and with complementary areas of focus, as follows:

    - The International Centre for Infrastructure Futures (ICIF), established to consider how infrastructure investment business cases could be developed for national and international projects
    - iBUILD (Infrastructure BUsiness models, valuation and Innovation for Local Delivery), established to consider how infrastructure investment business cases could be developed for local and city scale projects.

    Outputs from these initiatives should inform HM Treasury, the Infrastructure and Projects Authority and the NIC.

5) What changes are needed to the regulatory framework or role of Government to ensure the UK invests for the long term in globally competitive digital infrastructure?

54. Globally competitive digital infrastructure goes far beyond the provision of 4G or 5G telecoms or 500 Mb/s fibre to people's houses. Increasingly digital infrastructure is becoming part of many aspects of our core infrastructure systems including healthcare, transport, energy supply, communication, retail, banking and security. Among the most crucial issues facing the UK's digital infrastructure are how it enables intelligent off-peak charging of electric vehicles (EVs), how it can be used to manage distributed renewable generation to provide a stable and efficient electricity grid with more distributed power generation and active components such as electric vehicles and heat pumps and how it will facilitate the adoption of CAVs. This now means the loss of service on digital infrastructure has major societal effects.

55. The digital infrastructure has been shown to rely on the electrical power supply[21]. In future, the integrity of digital communication will also be essential to the correct functioning of the grid. Failure of either could bring down both and restarting them could be challenging. This evolution raises the question of who is the 'controlling mind' for future critical infrastructure systems. One might think that National Grid (NG) controls the electricity system but, if technology companies introduce millions of smart home energy management systems, those organisations could have much greater influence over instantaneous electricity demand than NG but without the legal duty to ensure supply security. In digital infrastructure there is no 'controlling mind': do we need one?

[20] One frequently cited example, that urban spend on improved cycling facilities could lead to a reduction in long term health issues, but there is currently no way of taking a cross-government view on this.

[21] Living without electricity, Royal Academy of Engineering, Institution of Engineering and Technology and Lancaster University, 2016

56. A similar situation will exist with EVs. As discussed in relation to Question 21, widespread adoption of EVs could potentially drive up demand to unachievable levels requiring some means of spreading peak demands. Smart charging control to avoid charging at times of peak load. Will be needed. One option for this could be price signals via time of use tariffs; setting very high prices at peak periods and very low when power is readily available. However, the consequence of this might be to heavily penalise those living in accommodation with no off-street parking, to disadvantage those unable to pay higher tariffs and to reward well-off owner occupiers with such facilities. Currently we have little understanding of appropriate solutions for this and work needs to be conducted in this area.

57. While there have been many futuristic statements about a digitally enabled future, policy makers need to ensure that the structures are in place to enable these, including tackling the growing interdependence between the energy, digital and transport systems.

6) What are the implications for digital infrastructure of increasing fixed and mobile convergence? What are the relative merits of adding more fibre incrementally over time compared to pursuing a comprehensive fibre to the premises strategy?

58. There are now few truly fixed connections; the reality of convergence is that almost all end devices are now connected via radio links - either WiFi or cellular - rather than being wired in. For example, a mobile smartphone might connect wirelessly to a cellular base station which has a fibre connection to a core network and thus to an Internet Service Provider (ISP). From the ISP, its virtual connection might again transit core networks to reach a small server linked to the internet via a WiFi connection and a router with a fixed broadband connection. In short, fixed and mobile have become essential elements of any connection. The issue is only how long is the radio link before it is tethered into a fixed network? In the home, the link is usually only a few metres before accessing a WiFi enabled router and onwards into a broadband network on copper, coaxial cable or fibre. Outside the home this varies from tens or hundreds of metres in dense urban areas to kilometres in rural areas (if there is currently coverage at all).

59. Other countries, notably the Irish Republic, have concluded that to facilitate an effective and competitive digital economy, universal high-speed broadband (minimum 30MBits/sec download and 6 Mbits/sec upload) delivered to all businesses and households is an imperative. If a comprehensive fibre infrastructure is implemented, new options will be opened up using 5G mobile technology in rural areas such that fibre might not need to reach absolutely to the premise and some cost optimisation could be achieved, though ongoing maintenance and upgrade costs for the radio elements may sharply limit this application.

60. There are economies of scale available in driving out fibre to the premise in a rapid rollout, rather than spreading the work out over many years through incremental implementation, and this should be factored into the analysis and decision-making. The fibre infrastructure thus implemented also supports the extended rural deployment of mobile communications through its use for backhaul of 4G (and shortly 5G) services and thus represents a double win. This said, the country needs the most cost-effective way of achieving the required levels of connectivity in any given situation. While there is currently a large amount of focus on fibre, the most cost-effective solution is likely to be more mixed; in some cases, fibre may be the best solution while in others it might be Fibre to the Cabinet (FTTC) and in others Direct Subscriber Line (DSL) broadband might be sufficient.

61. The need to conceive of digital infrastructure as a variety of forms of connectivity enabled by various fixed and mobile connection options means that important changes to the way digital infrastructure is regulated are needed. At present, there is separate regulatory environments for "fixed" and "mobile" operators and differing levels of attention given to radio spectrum for cellular connectivity compared to Wi-Fi or other forms. This can tend to prevent innovative new ‘converged’ solutions and offerings emerging or fail to give

enough focus to ideas that might have merit. The vision and plans for digital connectivity and the ongoing evolution of communications infrastructure need to break down the silos between fixed and wireless communication technologies and regulatory models.

62. Finally, a strategic approach should be taken to all major infrastructure investments in that they should contain fibre at the time of design and construction, since the cost of installation is lowest at this point.

7) What are the key factors including planning, coordination and funding, which would encourage the commercial deployment of ubiquitous connectivity (including, but not only, in rural areas)? How can Government, Ofcom and the industry ensure this keeps pace with an increasingly digital society?

63. There are many areas where there is insufficient connectivity. These include rural areas and poorly served old inner-city areas, buildings and trains. Each has differing challenges and solutions.

64. If rural and poorly served old inner-city areas continue to lag in terms of high speed broadband connectivity, then there will continue to be significant economic impacts from the hollowing out of local communities plus substantial social disadvantage in a world of that is fast becoming 'digital by default'. Roads and rural areas require cellular operators to deploy, however, where they have not done so already is due to economics. While assistance such as easing planning permission and allowing higher masts will make a small difference, it will not resolve the problem.

65. A key contribution to cost-effective rural deployment of fibre can come from leveraging local self-help groups wherever possible. This can dramatically cut the cost of civil works and issues around wayleaves can be greatly simplified. There are now many successful examples of such groups and government should examine what can be done to encourage these further. How could OpenReach, for example, best be given incentives to draw on such local and small business resources for fibre implementation but then provide ongoing professional service and support? Ultimately, however, where the economics are prohibitive to commercial entities, direct funding may be required to achieve specific coverage requirements; in some areas, this may be the simplest and most transparent solution. This is effectively already happening with the emergency service network contract that government have placed with EE which provides funding in return for better coverage.

66. Buildings require in-building deployments. The only solutions that have gained traction here are self-deployed WiFi routers. As phones increasingly switch seamlessly to WiFi, even for voice calling, this will become the preferred way to provide in-building coverage. Government can lead on this by making WiFi available throughout all public buildings, building on initiatives such as eduroam.

67. Trains are likely best tackled through dedicated backhaul provision to the roof of the train, with in-train WiFi deployments, as is currently being trialled by DCMS. It seems likely that the cost of this will need to be part of the infrastructure cost for train operating companies, and so absorbed into the ticket price.

68. Finally, mobile and fixed communications have a vital role in containing cascade failures of infrastructure and recognition should be given to the need to establish improved minimum standards for availability and resilience of the communications infrastructure, particularly in the context of back-up power. The role of a provider of last resort should be recognised and rewarded accordingly.

8) How can the risks of 'system accidents' be mitigated when deploying smart infrastructure?

69. In addition to the below we refer to comments in the introduction on the need to foster resilient learning organisations, cross-domain collaboration and effective systems engineering functions.

Cyber safety and resilience

70. In relation to achieving cyber safety and resilience, organisations need to be more aware of the vulnerabilities residing in components and products provided by their supply chain. Strong mechanisms are needed to ensure that cyber safety and resilience is maintained in all applications – both critical and non-critical - but there is no 'silver bullet'. All stakeholder organisations should be urgently addressing issues of cyber safety and resilience on an ongoing basis so that systems are built soundly from the bottom up and for subsequent generations. Different solutions will be required for different sectors. The UK must be outward-facing and sensitive to the various international regulatory contexts, which vary by sector. The risk of overly tight regulation needs to be balanced against a vital need for improved practice; government, industry, academia and regulators need to work together on a sector-by-sector basis, addressing different levels of criticality, to debate solutions that improve cyber safety and resilience, while ensuring that innovation and value generation is not adversely affected. While a sector focus is useful, it is also important to identify generic approaches to avoid duplications and support multi-sector supply chains.

71. The formation of National Cyber Security Centre (NCSC) is welcome. Its structure and capacity should be regularly reviewed to ensure that it can effectively address issues as they emerge. Robust principle-based frameworks are emerging in the UK and internationally, including those developed by NCSC. Where sector-specific frameworks already exist, NCSC and relevant government departments should ensure that they are fully adopted and operationalised. Where they have not already done so, government and industry sectors must adapt and operationalise general frameworks. Ideally frameworks should work across international borders. The UK can provide a leadership role, promulgating the exemplary frameworks it has developed for autonomous vehicles and the nuclear sector, for example.

72. Regulations must integrate safety, cybersecurity and resilience and protect consumers while also ensuring compatibility and usability internationally. As such, government must consider how the UK can maintain its influence on the development of international standards and regulations that blend safety and resilience after it has exited the EU, particularly in sectors that are important to the UK economy. Resources should be focused on strengthening cybersecurity expertise in regulators.

Safety and resilience in a smart 'systems-of-systems'

73. The growing interconnectedness of physical infrastructure with digital systems means that parts of the infrastructure system are increasingly interdependent and vulnerable to cyber attack or to failures in digital components, which again could lead to cascade failure[22]. There is a need to ensure these 'systems-of-systems' have adequate levels of safety and resilience. The following principles apply:

    - Physical and cyber safety, security and resilience must be treated as a fundamental system design issue from inception and must be kept under constant review throughout the life of an asset. Multiple layers of protection are essential.
    - Safety-critical systems using software often involve long and complex validation processes leading to approval whereas emerging cyber threats require very rapid actions to combat them. To reconcile these different requirements, a good system architecture is essential.

[22] The Royal Academy of Engineering is currently involved in a programme of work on the cyber safety and resilience of the digital systems that support critical infrastructure.

- The assumption that everything should be connected to the internet should be challenged, and both the benefits and risks explored. Each connected object can add to vulnerability from cyber attacks and cascade failures. In this context, whole system design is again very important.

74. There is a body of research around valuing resilience and interdependence that has contributed to HM Treasury guidance in the Green Book, and continues to be a valuable resource for NIC and industry[23]. A key resource is the emerging national infrastructure systems modelling capability being developed under the Infrastructure Transitions Research Consortium[24]. This will support the design and development of infrastructure systems based on a better understanding of availability and performance. An important aspect of that research is demonstrating the potential consequences of scenarios of infrastructure failure and disruption. Quantification of potential for disruption and systemic risks helps to justify the case for investment in resilience.

75. The degree of system planning and quality of incident management needs to be improved, both within individual infrastructure systems and between system operators. Understanding and communications between systems operators is limited and there is potential to improve cross-system performance through more consistent operating standards and strengthened operating protocols. This could include better links between, for example, transport modes and jurisdictions (such as TfL and Highways England) and between infrastructure system types.

76. A study on interdependencies in the infrastructure system by Engineering the Future[25] concluded that a resilient energy infrastructure is a priority given the interdependence of all other sectors on power. Any significant interruption to electricity supply in the UK will have severe economic consequences[26]. Future shifts in the energy system may further increase the UK's dependence on electricity, particularly if heating and transport become more electrified. This could heighten the detrimental impacts of electricity outages in the future. As noted in relation to Question 5, there will, in the future, also be an increasing interdependence between electricity supply and digital and transport infrastructure. Increasing levels of hybrid vehicles in transport with the simultaneous hollowing out of the fossil fuel sector by increased electrification also introduces a potential vulnerability whereby loss of transport fuel might then place more pressure on the electricity system.

77. The impact of Storm Desmond on Lancaster in December 2015 illustrates how cascade failure can occur, with wide-reaching consequences. There is much to be learned from this event[27], including:

    - Different models for locating responsibility for resilience will need to be considered, whether with individuals or service providers or some combination. It is clear that additional resilience is needed; where it is located in the overall systems requires more analysis.
    - At a local level, more needs to be done to educate local agencies so that contingency plans for service continuity take better account of the loss of electricity over an extended period.
    - There is considerable cost associated with providing standby arrangements that may be used only a fraction of the time, and also practical challenges in achieving

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[23] HM Treasury, Valuing infrastructure spend: Supplementary guidance to the Green Book https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/417822/PU1798_Valuing_Infrastructure_Spend_-_lastest_draft.pdf

[24] NISMOD (National Infrastructure Systems MODel) is the UK's first national infrastructure systems-of-systems modelling platform and database.

[25] Infrastructure, engineering and climate change adaptation, Engineering the Future, 2011

[26] Counting the cost: the economic and social costs of electricity shortfalls in the UK, Royal Academy of Engineering, 2014

[27] Living without electricity, Royal Academy of Engineering, Institution of Engineering and Technology and Lancaster University, 2016

this, including ensuring that standby assets are effectively maintained so that they work when needed. In the transport system, there may be a need for redundancy so that there is an alternative if one facility is out of commission.

- Another option is for regulators to allow greater rates of failure in the electricity or communications systems, but to ensure that there is a rapid-response mobile back-up system allowing services to be restored on a temporary basis. It is not clear whether this responsibility should fall to the privatised telecoms sector.
- The complexity of the infrastructure system is increased by the large numbers of participants sharing responsibilities and with different incentives to optimise their own part of the system, and the wide geographical and organisational distribution of each single critical system. Commercial or regulatory incentives – to maximise profit or minimise the regulated asset base – may work against total system resilience.

78. Each national regulator should appoint a person to lead on infrastructure resilience and related interdependencies. Each regulator should accept a duty of resilience and work with other regulators in a more joined-up way. Resilience audits could be considered as part of the reporting required to fulfil licence obligations. The activities of regulators and the Centre for the Protection of National Infrastructure also need to be more integrated, particularly in dealing with the risks of cybersecurity. The OECD or a similar body should introduce international benchmarking for resilience.

79. Methods for assuring complex systems of systems require further research. Support for the research ecosystem – including academia, SMEs and government agencies – should aim to accelerate the development of solutions for assuring complex 'systems-of-systems'. The challenges require multi-disciplinary approaches. Diffuse research areas such as cyber security, the Internet of Things and tools and methods for software engineering will need support, with strong links to industry and real-world application, since numerous different companies and players are involved in creating the relevant systems. This would allow the evaluation of large-scale behaviours of the system such as emerging properties and behaviour under failure or attack conditions.

80. While methods for assuring complex systems require further research, the UK has world-class centres of excellence in safety-critical systems, and has developed a range of tools and methods to produce and assure high quality software. These include scientific methods such as formal specification and verification, as well as engineering design and development methods, system monitoring, incident investigation, disaster recovery and methods of assurance. There is potential to transfer expertise from the safety-critical software community to other domains.

9) What strategic plans for transport, housing and the urban environment are needed? How can they be developed to reflect the specific needs of different city regions?

81. Considering transport, housing and the urban environment as an integrated system is key. For example, new housing has little benefit, if not also provided with good transport links, and other social needs, such as health and educational provision. Housing and transport go hand in hand – housing without transport leads to sink estates with socially deprived populations, whereas fresh transport schemes without enough users are rightly considered as failures. Furthermore, an ageing population will require greater accessibility and connectivity between homes and their day-to-day functional environments. Infrastructure plans need to address the future need for health and social care to be delivered in the home, in both urban and rural communities.

82. An example of a well-planned, integrated city, is Milton Keynes (MK). Fifty years on from the establishment of the Milton Keynes Development Corporation (MKDC), the city's unitary authority is still proactively growing the economy locally, and providing the services that the city needs to function appropriately. Following a master plan developed in the 1960s that created a new conurbation from a number of pre-existing towns and

villages, including the original small village of Milton Keynes, from which it derives its name, MK is now a stand-alone economic power house, which has been noted by the NIC. The NIC now see the development of the Cambridge to MK to Oxford corridor as one of the key national UK priorities for further development, considering transport arteries and connections of road and rail, housing, water and energy provision for this economic belt based on high value-added manufacturing and services.

83. MK is a good example of a planned infrastructure system, incorporating all elements required for a well-functioning city, servicing the needs of its population. Transport planning has been, and continues to be, a key consideration for the unitary authority of Milton Keynes Council and transport connections via road and rail have consequently been critical to the successful growth of the MK conurbation. However, the real success comes from the whole-system thinking, providing needs for the population and business alike. The first consideration was the provision and management of water, with the construction of two large balancing lakes, in Willen and Caldecotte. Housing and energy provision together with the effective use of land has enabled the city to continue to grow, and even now, 50 years on, land is available for further business and residential expansion. So successful has been the business growth that the authorities, MKDC, and now MK Council and the Parks Trust, have been major beneficiaries of the increased land values.

84. Despite the success of Milton Keynes, remains a relatively rare example of what can be achieved and, in general, joined up infrastructure systems thinking is lacking in the UK. The current UK infrastructure investment programme is huge, and with the Department for Transport being the largest capital spending department across central government, transport infrastructure investment is in need of more systems thinking to better serve the needs of society. This highlights the need for a body, such as the NIC, to promote integrated systems thinking.

85. A systems approach that considers housing and workplaces alongside infrastructure will help unlock future development potential, particularly where the housing crisis is most severe[28]. Housing, workplaces and infrastructure (both physical and digital) should be considered as a single, integrated system, with the planning system as the enabler. Dedicated upfront resource would allow infrastructure to be better integrated into the wider context, and the necessary steps taken to derive best value from a new asset.

86. Effective land-use policy is critical. There is much to be learned from continental cities that achieve lower journey distances and a lower share of travel by car by requiring higher density mixed development and building in public transport routes from the start. A critical issue is deciding dispositions of future bulk housing to facilitate anticipated growth, which currently happens in a largely unplanned way. Better planning is needed for the growth to occur in such a way as to create successful places. Housing and transport need to be considered together in national space planning, and housing in its bulk form should be the basic ingredient of the National Infrastructure Plan. A statement could be required for all major infrastructure schemes demonstrating how they contribute to housing growth[29]. Regulators also need to work together more closely, and collaborate, to gain best effect for the benefits of consumers and society.

87. It is also worth noting that the consultation question specifically addresses the urban environment but implies the housing and transport needs to be addressed are limited to city regions. In some ways, managing transport in cities is a relatively structured problem: there is usually a delineated central urban area (in which much of the economic activity takes place), suburbs and defined radial corridors between the suburbs and the centre.

[28] Crossrail 2 is one example of a transportation scheme enabling housing growth. Viewing housing and transportation as an integrated system would provide additional benefit to this project.

[29] This assumes that infrastructure provision is occurring ahead of population and housing growth.

88. The situation is less clear for areas that are not city regions but conglomerations of interlinked urban areas. An example would be the Lancashire towns of Warrington, St Helens, Wigan, Bolton, Bury, Rochdale, Preston, Blackburn and Burnley. This area includes these major urban centres, with populations up to 300,000, five of which are included in the Manchester City Region, and at least 20 smaller towns, interlinked by a congested road network. Although many people from this area commute into Manchester, a greater number work in their local urban area or commute to an adjacent one.

89. At present, the private car is the dominant mode of transport and, with the plethora of journey start and finish points, it is difficult to envisage an alternative. It is perhaps the type of area where a switch to electric vehicles would show greater benefits, in terms of CO_2 emissions, than in cities. Re-regulation of the bus services (as in London) could also allow better strategic planning of the dominant mode of public transport.

10) What sort of funding arrangements are needed for city transport and how far should they be focused on the areas with the greatest pressures from growth?

90. The text of the consultation document describes the scenario where property values rise significantly around new or enhanced transport hubs, leading to investments paid for by taxpayers generating windfalls for property owners. The document goes on to say: 'Taxing a small proportion of this increased value could provide a potential new source of revenue towards the cost of valuable infrastructure projects.'

91. The current system allows imposition of development contributions through Section 106 of the Town and Country Planning Act and through the Community Infrastructure Levy (CIL). But there is no mechanism for taxing increased property values. The principal issue arising from any attempt to tax increases in property value is that a direct cause and effect might be difficult to prove. Property value is created by many factors, not solely transport-related. Changes in value will therefore be affected by multiple factors. Isolating transport improvements from, say, new improved local green spaces, or a good new school opening in the vicinity, will not be straightforward. An increase in property value also results in increases in rateable value or Council Tax band. Arguably, the city administration benefits from rates revenues proportional to the sum total of all changes, good and bad, and perhaps the main effort should be in finding new, transparent ways to evaluate public infrastructure's contribution to a property's rateable value, which should then lead to meaningful discussions within cities for proportional allocations of budget for transport improvements, based on a fair share of the total rates paid by business and domestic ratepayers.

92. The second part of the question asks how far funding should be focused on those areas with the greatest pressures from growth. In an integrated nation, there may be social connectivity and participative issues that should be considered alongside satisfying economic growth. A connected Britain is important for all towns and cities forming the hinterland of the current growth engine of London and the South-East. A well-connected UK will also facilitate growth of new centres of economic activity. So, restricting new investment in transport to areas of highest growth reinforces existing issues of economic inequality, and stifles the nurturing of new locations that may be ideally suited for high growth, but have not yet achieved it due to infrastructure shortcomings. There are a great many successful areas that would not thrive without good transport links; examples include Canary Wharf without the Jubilee Line Extension and Cambridge without good road and rail links to London. Strategically planned infrastructure can be both a wealth creator and distributor, reducing inequalities across the nation.

11) How can the Section 106 and Community Infrastructure Levy regimes be improved to capture land and property value uplift efficiently and help

93. Any new housing development requires the economic infrastructure to allow in/out movements of people, utilities (such as water, gas, solid and liquid waste and digital) and the social infrastructure that allow for quality education, healthcare, retail and leisure

activities. As such, it is an extremely important consideration to ensure that sufficient planning attention and financing is dedicated to ensuring that such economic and social infrastructure in adequately funded. This said, there are some issues that should be highlighted with regard to the Section 106 and Community Infrastructure Levy (CIL) regimes.

94. Section 106 is part of planning process and is seen in the industry as too 'loose' and requiring (often lengthy) negotiation. The outcome and time it takes to secure an outcome is thus unpredictable and not easy to incorporate into assessments of the viability of projects. The experience of 'users' within industry is therefore that it is unfriendly. Given that negotiations under Section 106 can take a long time and that they then trigger payments, this can lead to a tendency to delay projects. There can also be inconsistency across Local Authorities regarding how Section 106 Agreements are applied. Developers can end up feeling exposed to extra risks and this can impact on the provision of affordable housing - safeguards are needed to ensure that affordable housing does not get negotiated out of schemes by the use of the Community Infrastructure Levy (CIL).

95. While the CIL has helped counter some of the above issues, it is also seen as too rigid and has been perceived to suppress land value and thus the result can be to work against incentives for development. The fundamental basis of Section 106 is that the value of land increases with the arrival of better infrastructure, however, it is the resultant use of (or lack thereof) and economic activity that subsequently takes place on land that may, in due course, result in an uplift in land value.

96. One view is that this suggests that business rates and Council Tax, more often revised as values increase, are the most appropriate way to capture the benefits of infrastructure investments in an area and any resultant uplifts in land value. The Academy recognises that this is not necessarily a politically attractive solution since, for example, there will be incumbents who will argue that they did not want new economic infrastructure, however, approaches that seek to capture the uplift in value from infrastructure investments before such an uplift has been realised risks exposing potential developers to a great many upfront commitments which may result in stifling the provision of infrastructure and housing.

12) What mechanisms are needed to deliver infrastructure on time to facilitate the provision of good quality new housing?

97. This question is very broad, however, as highlighted in the answer provided to Question 11, any new housing development requires the economic infrastructure to allow in/out movements of people, utilities (such as water, gas, solid and liquid waste and digital) and, depending upon the development's scale, the social infrastructure that allow for quality education, healthcare, retail and leisure activities. The infrastructure required depends upon the specifics of the development site (ie, whether it is local infill, city centre regeneration, the development of previously used land or new greenfield development).

98. The failure of the so-called 'ecotowns' in the 2000s was at least in part because they focused almost entirely on housing provision and did not include economic and social infrastructure. For example, a number were redundant military bases that had poor transport infrastructure. Much more holistic planning is required and this requires vision, direction and leadership. There is no 'silver bullet' in terms of mechanism by which such planning and the associated infrastructure delivery is achieved, however, approaches that can tie the delivery of infrastructure to possible solutions to the housing (explicitly) such as densification, building on the greenbelt, tall buildings and their appropriate use should be developed in design policies and case studies developed by, for example, the Commission for Architecture and the Built Environment (CABE) on good planning and design of built environments provide useful examples[30].

[30] Case studies, Commission for Architecture and the Built Environment, 2011

99. Another key principle is to ensure that the correct mix of expertise is inputted early on into the planning and design process across the breadth of the economic and social infrastructure that is required. In addition to planning and urban design expertise, it is vital that this covers all the necessary engineering considerations – such as the provision of utilities like water - and should also include the views of relevant infrastructure providers and operators as well as communities, government agencies and relevant local and regional businesses. This would ideally lead to the development of shared objectives as well as an agreed, time-phased masterplan, which would allow early consideration of funding and financing requirements. It may be that such systematic considerations could be overseen by the relevant Local Enterprise Partnerships (LEPs), but if so LEPs should act as an honest broker rather than a project owner.

13) What will the critical decision factors be for determining the future of the gas grid? What should the process for deciding its future role be and when do decisions need to be made?

100. This is an important question and the Academy is pleased to see it receiving examination as part of this consultation. We have, however, not been able to marshal sufficient input and evidence on this to formulate an informed response.

14) What should be the ambition and timeline for greater energy efficiency in buildings? What combination of funding, incentives and regulation will be most effective for delivering this ambition?

101. The Academy's past analysis has concluded that energy demand reduction across the whole economy will be essential to meeting the energy trilemma of secure, affordable, low-carbon energy[31]. Ambition for demand reduction must therefore be high. Though demand reduction is of high importance across all sectors, the biggest immediate wins are to be found in the domestic heat sector and urgent action is needed to radically improve the thermal efficiency of the UK's housing stock.

102. Demand reduction in the heat sector encompasses the following:

- Energy efficiency measures in buildings: such measures often do not deliver the theoretical savings and this design and performance gap needs to be addressed through improving models, research into product performance, ensuring competence of suppliers and installers, understanding of occupier behaviour and better enforcement of building regulations.
- Retrofitting existing buildings: new build is important but the majority of buildings that will be around in 2050 have already been built. A concerted effort on research and innovation is needed in this area. A greater willingness to use regulatory measures to drive a minimum level of energy-efficient refurbishment needs to be developed, possibly by extending some of the policies and minimum legal requirements that currently apply only to new build. Innovative solutions that go beyond the legal requirement may be achieved through the deployment of voluntary industry standards to promote higher performance.
- Technical, process and financing innovation: in the medium term, this will be needed to deliver net-zero-energy retrofit as a one hit solution for UK buildings as with, for example, the Dutch "Energiesprong" model. New build properties also need to move immediately to a net-zero-energy requirement. Again, the use of voluntary industry standards may accelerate adoption of a net-zero-energy requirement, where this is seen as a market differentiator rather than a matter of legal compliance.
- Skills: a sufficient and well-trained workforce to install and maintain efficient low carbon domestic and commercial heating systems is crucial to demand reduction.

[31] A critical time for UK energy policy: a report for the Council for Science and Technology 2015. Royal Academy of Engineering

- Learning lessons: lessons must be learned from initiatives that are succeeding, especially large-scale city schemes in the UK and abroad that coordinate actions across multiple stakeholders. Lessons can also be learned from less successful initiatives.
- Commercial drivers and consumer needs: there is a need to understand the commercial drivers of the construction industry and the needs of consumers. Schemes that conflict with either of these will fail.
- Understand new technologies: different technologies will work best in different locations and for different consumers, and this needs to be explored. Heat pumps, heat networks, biomass and others will all have their place.
- Community energy efficiency schemes: there is considerable scope to explore the opportunities and potential of different models of community level engagement.

103. For a number of the areas above, recommendations made in *Each Home Counts*, a review of consumer advice, protection, standards and enforcement in relation to home energy efficiency and renewable energy measures in the UK, have the potential to deliver improvements.

15) How could existing mechanisms to ensure low carbon electricity is delivered at the lowest cost be improved through:

- **Being technology neutral as far as possible**
- **Avoiding the costs of being locked in to excessively long contracts**
- **Treating smaller and larger generators equally**
- **Participants paying the costs they impose on the system**
- **Bringing forward the highest value smart grid solutions**

Cost of energy

104. To date, the government's multiple interventions and the resulting patchwork of policies governing the energy sector have resulted in non-optimal outcomes and a complex landscape. Firms and investors struggle to understand and navigate this landscape, making it difficult for them to have confidence when making significant long-term investment decisions. The current system is also heavily bureaucratic for many players including generators and network operators. A clear vision for the future of the whole energy system is needed and should be based on technical evidence, regulatory innovation and clear political decision making. As part of this, it may be valuable to consult investors on factors that could facilitate private investment in UK low carbon infrastructure.

105. The great many trends that the energy system is expected to need to accommodate require a robust framework providing resilience and within which firms can have confidence to invest and innovate. The major trends that need to be accommodated in this framework include the likely increase in demand from electric vehicles, potential electrification of heating, the transition from a commodity market to a capacity market for electricity, an increase in distributed supply and storage and hence a need for an increased role for distribution network operators, and an increase in digitalisation that will have impacts across the system.

106. The Academy sees significant value in a systems engineering approach such as that being examined in the Future Power System Architecture Project[32]. A 'system architect' should be able to perform a long-term analysis of the whole system, set out the needs of the system, and an overarching vision for how these should be achieved. This vision should be based on evidence, including from modelling studies and scenario analyses performed by independent groups such as was carried out by the Energy Technologies Institute. A vision for the system would need to incorporate overtly political decisions, such as the contribution or absence of nuclear or carbon capture and storage (CCS) technologies from the UK's energy mix. Such decisions are needed in a timely manner

[32] Future Power System Architecture, Energy Systems Catapult, 2017

and should integrate technological evidence. A vision for the system must also be flexible and adjustable to allow for changes in technology or other external factors. One possible means by which uncertainty of a policy could be further reduced would be to publish with the policy a prescription of how the policy will be adjusted to keep the intended outcomes within a defined range.

107. A key uncertainty is how technological innovations, consumer behaviour, and business models interact in the energy system. These interactions and their impacts cannot readily be hypothesised or modelled. The Academy therefore recommends that real world demonstrators are established, encompassing the whole energy system. These should include the full pathway from supply to demand, and include heat, transport, waste, and electricity, and both domestic and industry consumers[33]. Such demonstrators will be essential to provide real world, whole system evidence of how technologies will integrate and how different options will function effectively for all stakeholders. This would provide valuable means of examining, for example, how distributed generation, demand management and storage technologies will integrate with centralised generation, and explore regulatory, commercial and technological factors. Pilots must be run at significant local or regional scale, building on the smaller or single-technology demonstrations carried out to date. The Industrial Strategy Challenge Fund challenge, *Prospering from the energy revolution*, would be an excellent opportunity to develop such whole system demonstrators.

108. The whole energy system needs to be considered in its entirety, for example, costs are currently considered and managed differently across different parts of the energy sector. For example, taxes on liquid fuels are an order of magnitude greater than those on gas and electricity, indicating that the aim of low energy costs is not consistent across different policy areas. Indeed, taxes on liquid fuels effectively function as a subsidy for electric vehicles. There will also be complex interactions between energy policy and other policy areas such as congestion management or road pricing, and the technology that may influence them, such as smarter roads or autonomous vehicles.

109. Since changes in any one part of the energy sector will significantly impact others, and indeed that energy policy will interact with other policy areas, we recommend that a systems approach that places meeting the energy trilemma - of secure, affordable and low carbon energy - as its central focus should be applied to any review of the energy system and its future direction, rather than a narrow focus on electricity (a sub-system of the overall energy system), as is the focus of this consultation question.

Electricity generation

110. The electricity generation market should ideally be technology neutral and market-driven but this has challenges for implementation in practice. Historically, many government energy policies have aimed to be technology neutral but, in practice, this has favoured certain types of generation due to differing levels of progress and deployment. This has led to further government adjustments to compensate for unintended imbalance, leading to the complex layering of policies. This highlights the difficulties of being 'technology neutral' in the energy sector, where policies may support certain technologies as a necessary intervention in the short term but which do not lead to optimal solutions for the energy mix in the long term.

111. Additionally, the scale and capital cost of investments in some areas of the energy sector, such as nuclear power or large tidal schemes, mean that political support is required to bring them into practice, making 'technology neutrality' impossible. Here we refer to comments made in our response to question 4, regarding cost benefit analysis and the challenges involved in assessing on equal terms projects with very different

[33] A critical time for UK energy policy: a report for the Council for Science and Technology 2015. Royal Academy of Engineering

characteristics, including life times and degrees of intermittency (including varying predictability in intermittency).

112. All energy schemes have different attributes. For instance, nuclear should be run at full load whenever possible but produces nuclear waste which difficult and costly to deal with. Solar varies with weather conditions with limited predictability, and cannot generate at night. Since the peak energy demand normally occurs on a winters evening, solar power offers nothing at this time. Wind power is also variable and generally delivers higher average output over the winter when demand is also higher but can also cease production during a winter high pressure weather system for a week or more. At present all such schemes have operational lifespans of about 25 to 50 years. Hydro power is flexible, and long life, albeit it may be constrained during drought periods, when solar output would be highest. Tidal range has a high capital cost and its output is variable but predictable with its core infrastructure remaining functional for up to 100 years or more. Each of these attributes either increases or reduces the value of the asset but their different combinations make assessing the value for money between technologies challenging, for example, the normal Treasury discount system does not include allowances for intermittent operation.

113. To take the example of tidal power in more detail, the costs quoted in table 4.1 in the consultation document are £216-£368/MWh which are not cost effective. However, the assumptions used to arrive at these figures are not clear and may not adequately take into account the attributes of tidal power. As stated above, tidal range schemes are high capital cost and long-lived. Unlike other forms of generation, which need to be replaced after 35 to 50 years, tidal range could have an operational lifespan of 100 years or more, albeit with an updating of some of the electrical components required. The Contract for Difference (CfD) costs are greatly dependent on the conditions applied, the length of period during which the capital costs would need to be recouped, and the interest/discount rate that has been assumed.

114. In contrast, Charles Hendry's review of the role of tidal lagoons[34] received evidence from Tidal Lagoon Power that the required strike price for the first operating year for their proposed Cardiff, Newport and Bridgwater tidal lagoons would be in the range of £105-£120/MWh - believed to be for a 35 year period. After the initial capital write off phase, the energy costs for the rest of the scheme's life were expected to be appreciably lower and costs would reduce to £90-£115/MWh after a pathfinder project had been built and operated. Similarly, LongBay SeaPower and Halcyon Tidal Power have proposed a 5TWh/y tidal lagoon off West Somerset which they claim would provide electricity at <£90/MWh/y during the capital write off phase and £65/MWh/y thereafter[35]. It should also be noted that innovations in scheme design or in technologies can also significantly reduce the costs of tidal power, for example, with some schemes considering much cheaper turbine designs. As such, it is important in this area and with other forms of generation not to consider costs as static over time.

115. Contrary to the costs quoted in the consultation document, these figures suggest tidal energy schemes available to the UK may well be cost effective if its particular benefits of predictability and long life are properly included in the assessment. This example illustrates the need to overcome some of the current shortcomings in CBA highlighted here and in relation to question 4. The government has recently held a successful Contracts for Difference auction in which wind power showed significant cost reductions demonstrating that, where possible, competition is often the most successful means of driving cost reductions.

116. The challenge of ensuring technology neutrality in the energy sector adds weight to the importance of an overarching systems engineering approach and an overall 'system

[34] The Role of Tidal Lagoons, Charles Hendry, 2016

[35] Press Release Jan 16th 2017, LongBay SeaPower and Halcyon Tidal Power, 2017

architect'[36] who can set out a long-term vision on which interventions and investments can be based.

Energy transmission and distribution

117. While the original intention behind the eight year timeframe for periodic review of regulation of network operators - to provide certainty for the sector – was a positive one, it has proved too long in a sector experiencing such rapid technological change. The need to incorporate more smart grid solutions, an increase in distributed generation, an increasing role for regional networks, and a decrease in differentiation between generation, distribution and supply will all impact the work and business models of network companies significantly in the coming decades. Particularly, there is likely to be a major shift in the management of the national electricity infrastructure from a national to a regional level.

118. The distribution network operators will play a key role in driving and delivering these changes, and so there is good reason for a shift from distribution network operators to regional or distribution system operators – something proposed in the recent Helm Review. It is considered that some (but not all) of these operators are prepared and ready to adapt to these technological changes. However, they would benefit from the establishment of a clear government framework to support business investment going forward.

119. For example, in relation to electric vehicle infrastructure it is currently unclear where responsibility will primarily lie for investing in, developing and maintaining charging points. This could sit with network operators, companies such as automotive fuel brands, independent firms, or a mixture of these organisations. The optimal solution will depend on many factors including the role of electric vehicles in the transport system in different regions of the country and road system, as well as social and political factors such as access to charging facilities for all customers (see response to question 21). Indications from government of the desired outcome for electrical charging points, networks, and the role of electric vehicles in the transport system will be important to allow the market to make decisions and investments efficiently and effectively.

Digitalisation

120. Digitalisation is set to have a significant impact on the energy sector, as it is across the whole economy. Digital technologies will drive change in every part of the energy system, from smart meters and appliances in domestic houses, to the use of data to better manage supply and demand (including variable tariffs for domestic customers) as well as convergence across energy networks, to connected control systems for major power stations. This should bring many benefits, including improved performance and innovation. It will be vital for the government to provide continued support for such changes as outlined in the government's industrial strategy and the *Made Smarter* review, including through the development of digital skills[37].

Innovation

121. The increase in public research, development and innovation funding for the energy sector, as set out in the Clean Growth Strategy[38] and the Industrial Strategy Challenge Fund[39], is very welcome. Public funding for energy research, administered primarily through the component organisations of UKRI, is largely balanced and appropriate. The multitude if research organisations and institutions working on the energy system brings several advantages. These include allowing them to focus on complementary challenges and approaches and continuously building standards through competition.

[36] Future Power System Architecture, Energy Systems Catapult, 2017
[37] Made Smarter Review 2017, Department for Business, Energy and Industrial Strategy, 2017
[38] The clean growth strategy 2017. HM Government
[39] Industrial Strategy: building a Britain fit for the future 2017. HM Government

122. It should be noted that in many areas of the energy sector, such as the use of hydrogen in domestic heating or Carbon Capture and Storage (CCS) technologies, the innovation bottlenecks are in large scale demonstration and deployment of these technologies, rather than basic research or early pilot demonstrators. It is therefore important that innovation funding is focused on real world demonstrator projects and the transition to commercial-scale deployment, as well as more fundamental research and development. It is also key that levels of funding are sufficient to achieve the aims and goals of innovation projects. Where support is required to translate innovation to commercial large scale deployment, such as in the use of hydrogen or CCS, it should be recognised that funding levels required to make a significant impact will be substantial due to the large scale infrastructure involved.

16) What are the critical decision factors for determining the role of new nuclear plants in the UK in scenarios where electricity either does, or does not, play a major role in the decarbonisation of heat? What would be the most cost-effective way to bring forward new generation capacity? How important would it be for cost-effectiveness to have a fleet of nuclear plants?

123. The Academy's report *A critical time for UK energy policy*[40] highlighted the importance of new nuclear build within the UK energy system and the significant role that new nuclear plants could play. Given a strong new build programme, at the time of writing (2015), analysis suggested that nuclear capacity in 2030 could be as high as 15 GW. However, it was stressed that, if new build stalled, it could be as low as 5 GW, which would be a major concern. The report highlighted that a key early warning sign will be if only one final investment decision had been taken on new plant before 2020, at the time of writing, this included the decision on Hinkley C.

124. Much good work has been done with regards to generic design assessments and sites for new build, however, difficulties arise from the very high capital costs required and a small number of potential developers. Few developers limit the opportunity to drive down costs through competition for CfDs. Maintaining policy stability is important, but, beyond that, success of the current generation of new build projects is largely in the hands of the developers rather than requiring further policy intervention. However, government is encouraged to consider whether any alternative policies beyond those currently being followed might help increase the capacity of nuclear power with particular consideration given to smaller reactors. Beyond the current raft of Gen III reactors, small modular reactors (SMRs) might offer an alternative with easier financing (smaller units, shorter build time) but as yet there are no commercially available options and therefore unknown £/MWh performance. Finally, support from government is needed across the whole nuclear research and innovation landscape to revitalise the UK's position at the forefront of global developments.

17) What are the critical decision factors for determining the role of carbon capture and storage in the UK in scenarios where electricity either does, or does not, play a major role in the decarbonisation of heat? What would be the most cost-effective way to bring it forward?

125. Carbon capture and storage (CCS) has the potential to deliver secure, low carbon electricity and, in many scenarios for the UK energy system, it is seen as a critical technology[41]. Its main advantage is to enable the continued use of fossil fuels while avoiding most of the carbon emissions. Ultimately, the potential of negative emissions through the use of CCS with biomass should also be an option and this is coming under close scrutiny, given the current indications that so-called negative emissions technologies will be required if long-term climate targets are to be met[42]. However, while the technical challenges are understood and present no serious concerns, this technology

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[40] A critical time for UK energy policy, Royal Academy of Engineering, 2015
[41] A critical time for UK energy policy, Royal Academy of Engineering, 2015
[42] UK climate action following the Paris Agreement, Committee on Climate Change, 2016

remains largely unproven at commercial scale and significant questions remain over its technological and economic scalability. As such, with no full-scale demonstration plant in the UK, the key need in this area is demonstrator projects. A way needs to be found to make CCS economically viable, and this will only begin to happen when the technology is fully demonstrated at scale.

126. With this technology already being developed in North America and China, the UK will need to act fast of it wants to contribute to the world market in this technology. If it does not, decarbonisation of the electricity system will be at serious risk. Any investments made in demonstrator projects will need to be front-loaded and the construction of pipeline networks coordinated in the early stages of infrastructure development, as these will be valuable, long-term shared assets. Indeed, the beginnings of a transportation network for carbon dioxide that allows follow-on projects would perhaps be the most important development from any demonstration projects.

127. While the increase in public research, development and innovation funding for the energy sector, as set out in the Clean Growth Strategy[43] and Industrial Strategy Challenge Fund[44], is very welcome this will resource basic research and early pilot scale activity. It is not going to service the need that exists with CCS (as well as other areas, such as the use of hydrogen in domestic heating) for largescale demonstrator initiatives. Where support is required to translate innovation to commercial large scale deployment, such as in CCS, it should be recognised that funding levels required to make a significant impact will be substantial due to the large-scale infrastructure involved. Innovation funding for these areas must recognise the scale of the challenges faced and funders will require appropriate resources, capacity, and governance structure to deliver such large-scale demonstrators.

18) How should the residual waste stream be separated and sorted amongst anaerobic digestion, energy from waste facilities and alternatives to maximise the benefits to society and minimise the environmental costs?

128. The Academy has not addressed this question as part of its response.

19) Could the packaging regulations be reformed to sharpen the incentives on producers to reduce packaging, without placing disproportionate costs on businesses or creating significant market distortions?

129. The Academy has not addressed this question as part of its response.

20) What changes to the design and use of the road would be needed to maximise the opportunities from connected and autonomous vehicles on:

- **motorways and 'A' roads outside of cities?**
- **roads in the urban environment?**

How should it be established which changes are socially acceptable and how could they be brought about?

130. Firstly, the question implies autonomous operation being restricted to main roads and in the urban environment but many of the claimed benefits of connected and autonomous vehicles (CAVs) are dependent on them being able to operate anywhere, door-to-door, with users who, because of age, infirmity or inclination, are not able to drive. Furthermore, there are a great many unresolved issues and questions that impinge on this question.

Transitional issues and questions

[43] The clean growth strategy 2017. HM Government
[44] Industrial Strategy: building a Britain fit for the future 2017. HM Government

131. There are a great many practical and technological issues relating to CAVs around which there is currently uncertainty but which have significant implications for road design and use, these include:

- CAV response to certain conditions: It is currently uncertain how CAVs could and should respond to range of disruptions to normal road use, for example, flood or debris blocking the road or for certain conditions such as heavy snow cover. What actions (such as mounting the pavement, etc.) vehicles may or may not be capable and authorised to perform has implications for road design and management.
- Interactions with other road users: There are questions of safety and confidence if pedestrians and cyclists are to use the same space as CAVs and unresolved issues around how they will interact. For example;
    - Sometimes drivers stop, blocking following traffic, to allow a parent with children or an elderly person to cross the road, often such interactions rely on eye contact and body language as a means of communication.
    - Whether CAVs can be designed to coexist with cyclists under all circumstances is yet to be proven, for example where cycle lanes are indicated on footways and then transfer to the road or where the road layout encourages cyclists to pass a car on the nearside and occupy the cyclist box at traffic lights.
- Behaviour changes: As CAVs become more widespread, other road users are likely to adapt their behaviour to take advantage of the known behaviour of automated cars, for example, becoming more reluctant to wait to cross the road and instead forcing CAVs to stop. Pedestrians, cyclists and human drivers may start to assert priority during interactions on roads.
- Risk taking: The existing road system only works because drivers take risks. Sometimes a driver can only merge with traffic by taking a gamble that another driver will slow down to let them in. If CAVs are to operate alongside human drivers on busy UK roads with roundabouts and unsignalled side roads, the vehicles have to be able to take risks otherwise they could become stuck, waiting for a risk-free gap in the traffic. In such circumstances, CAVs will need risk algorithms that works out, for example, the probability of another vehicle on a roundabout not taking the anticipated exit or not braking.

  How these problems are resolved is currently under debate, development and testing but they have implications for whether and under what circumstances CAVs and other road users can coexist and what road conditions and circumstances CAVs can and cannot manage.

132. During the period where highly automated cars are not the dominant vehicle type, the above factors may lead to more accidents than there are at present because of the changed behaviour of road traffic and other road users. This needs detailed simulation and analysis because, if these scenarios occur and are considered unacceptable, segregation of CAVs from manual driving will be required which will in turn require changes to road layouts, signals and barriers to keep pedestrians and cyclists out of the areas reserved for CAVs. Transitional issues will need to be considered to enable driverless and non-driverless systems to interact and function together. Further study is needed in this area to affect the roll-out of the new technology, which may include segregation of road infrastructure at some stages to separate driverless with non-driverless systems.

Enabling systems

133. Some fundamental enablers of CAVs will be required, such as a 3D map of the road infrastructure, which is a dependency for the effective functioning of driverless systems. Some work has progressed on this, around targeted projects in the Milton Keynes area and other city demonstrator areas, however, ultimately, the entire road network will require mapping, to enable driverless system operation. The priority is likely to be in urban environments first, followed by the strategic road network. This, however, raises

the question of which organisation is responsible for providing the mapping used by CAVs and what are the implications of a vehicle using out-of-date maps?

134. The alternative to stored maps would be a permanent connection to the internet and regular download of local mapping information but, if this is to be used in a safety-critical way, which organisations would be responsible for the transmission infrastructure and how would the resilience of the transport system be affected by a loss of the data link – for example, caused by a loss of the electricity supply? Liability becomes more complicated if elements of machine learning are incorporated into the CAV software. In the same way that some car drivers share their experiences on a website, it is plausible that CAVs from a particular manufacturer could share experiences so all learn from experiences of each other. Is such a system likely to establish a machine 'groupthink' and, if so, does it affect the liability of the original designers?

135. Connected vehicles will require a robust, reliable, secure and fast wireless communications system to enable the transmission of data between vehicles and roadside infrastructure. In the long term, this might remove the need for expensive sign and signal gantries and other equipment such as CCTV, Speed Cameras and Radar Detection. The removal of such equipment and supporting structures will also reduce the need for vehicle restraint systems. The result will be a much 'cleaner' appearance for high speed roads. Older vehicles, not equipped with navigation or information/entertainment screens can be provided with after-market devices to enable the receipt and display of information, akin to the TV Digital Switchover and provision of digi-boxes.

Road design

136. The needs of CAVs vary significantly depending on the level of automation and the use cases. A likely, initial, scenario is the use of autonomous driving once in a lane on a high speed road with a driver navigating to and from the lane at the entry and exit slip roads. Once in lane the autonomous mode could enable the operation of the vehicle independently of the driver which would require high quality, unambiguous and consistent lane markings. The lane widths could be reduced as a vehicle driven by a machine would not need the 'wriggle room' required by human drivers and could drive closer together side by side. Such narrower lanes could only be used by autonomous or highly automated vehicles. Autonomous vehicles would also need a robust communications system to enable cooperation and shared learning between vehicles.

137. For fully automated vehicles to realise the full benefits that have been extensively advertised, road designs will need to be analysed in the light of the planned behaviour of automated vehicles. As highlighted by the preceding discussion, this must vitally include the interaction between CAVs, other road users, including cyclists and pedestrians. It must also include behaviours under conditions of extreme weather, repairs to the road surface, maintenance of bridges, failures of vehicles and accidents. If automated lorries are to drive at speed in convoy, road layouts may need extra safety features. If cars are to drive at higher speeds to take advantage of the safety features of automated vehicles, then bends and camber may need to be recalibrated and adjusted.

138. Roads may require instrumentation to allow the police and traffic authorities to detect and control traffic remotely and to provide the data that allows CAVs to make optimum decisions (though it may be possible to achieve all this through automation in the vehicles).

139. Since we can continue to expect that the vehicles on UK roads will come from all over the world, all of this is dependent on effective and appropriate international standards for vehicle behaviour and data interchange.

140. Considerable thought will need to be given to cybersecurity and the consequences of a successful cyberattack on the vehicles, the infrastructure, or both. A fleet of autonomous cars or a petrol tanker, if control can be seized, can be weaponised. If CAVs and their

enabling systems are implemented, denial of service attacks must also be protected against since these could conceivably cause serious economic damage.

21) What Government policies are needed to support the take-up of electric vehicles? What is the role of Government in ensuring a rapid rollout of charging infrastructure? What is the most cost-effective way of ensuring the electricity distribution network can cope?

141. GB annual electricity demand in 2016 was 306 TWh[45]. There are a large number of uncertainties regarding how this will evolve, however the scenarios produced by National Grid (NG) electricity demand range between 321 TWh and 383 TWh by 2050. Cars, taxis and light vans cover about 600 billion km per year on Britain's roads. If we assume that, at some time in the future, 80% of light vehicles could be EVs or PHEVs, 75% of their mileage will be provided by electric power and a BEV or PHEV (on electric power) uses 0.15 kWh/km, there could be an annual demand from EVs of 54 TWh. This represents an 18% increase over the present UK consumption[46]. This is manageable.

142. The maximum demand on the GB electricity system is around 55 GW. Taking, for example, a scenario of 30 million EVs all plugging into 7.5 kW chargers at the same time, the peak charging load would be 225 GW, four times the present maximum. That, of course, will never happen but relying on the diversity of EV owners arriving home at different times is unlikely to reduce the peak by more than a factor of 4, still doubling the present peak demand and requiring wholesale replacement of distribution systems.

143. This illustrates the importance of 'smart' control of charging systems to take power when renewable energy is readily available, for example, in the early hours of a windy winter's morning or early afternoon on a sunny summer's day. However, it is not clear that the present smart meter systems, the structure of the industry or its regulation are capable of this degree of flexibility. Because of uneven geographical take-up of EVs, it is likely that Distribution Network Operators (DNOs) will need to be heavily involved in local load-shifting but this is incompatible with the nationwide retailing structure or the role of electricity retailers in the smart grid system. Present policies are not addressing this issue.

144. Any smart charging solutions implemented in conjunction with dynamic time-of-use (ToU) tariffs will require the careful application of whole-system thinking since there is a risk that a market movement from a high price half hour to a low price half hour could trigger the near-simultaneous switching of a large number of EV chargers. With projected EV numbers in the early 2020s, this step-change in demand will be far more than the System Operator's holding of fast reserve generation, potentially triggering a national system failure. Although a co-ordinated technical/market solution should not be too hard to develop, at present there is no organisation charged with finding it.

145. Though no ToU tariffs have been introduced as they rely on smart meters, which have not yet gone live in sufficient numbers, ToU tariffs are expected to be managed nationally, through electricity retailers. ToU tariffs created by national electricity retailers will, however, be largely useless in managing the geographical disparity of loads; a 'postcode-level' degree of granularity in any arrangements will be required. This will present challenges of public acceptability – via complaints of a 'postcode lottery' for electricity - but the alternative would be large-scale reinforcement of the DNO infrastructure in certain areas, with unpopular and expensive roadworks. Whether such a local load-sharing arrangement would be managed by the DNOs or by local residents' energy cooperatives or by some other means requires clarification.

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[45] Future Energy Scenarios, National Grid, 2017

[46] NG calculations are less optimistic about uptake and indicate a long-term increase of anywhere between 15 TWh and 25 TWh, depending on the energy scenario.

146. A 2013 study by the Energy Technologies Institute[47] showed that approximately 60% of UK homes were suitable for off-street charging; from surveys, they concluded people's preferred charging solutions, in order of preference, were: 1) at home; 2) at a workplace; 3) leisure or shopping location. People with off-street charging will be able to take full benefit of variable tariffs but these may not be available to the 40% who will have to rely on public charging infrastructure.

147. Many early charging schemes were in a limited geographic area with nominal 'membership' fees or were provided free by organisations who were keen to demonstrate environmental credentials. A widespread roll-out will require full-cost pricing. The costs of procuring and connecting-up a weatherproof and vandal-resistant charging point in a residential street, complete with smart card reader, Wi-Fi connectivity, remotely resettable protection systems, etc. is several thousand pounds. If it is used mainly by people who plug-in their EV at 18:00 after work and unplug it at 08:00 next morning, the value of the electricity sold will not pay for the cost of the equipment unless the unit price of electricity is much greater than the wholesale price. Present policies do not address the imbalance between what will be paid by those who have off-street parking who will pay much less for energy than those who will need to utilise other charging infrastructure.

22) How can the Government best replace fuel duty? How can any new system be designed in a way that is fair?

148. In 2015, a group of Academy Fellows produced *The transport congestion challenge*[48] this report investigated a range of technologies and policy measures to tackle congestion, reviewing them for their cost, congestion reduction potential and value for money. Of 18 front runners, efficient road pricing was considered to offer the best value for money and strongest congestion reduction potential across both the inter-urban and urban road networks.

149. The Department for Transport's 2015 road traffic forecasts predicted a 60% increase in congestion on the Strategic Road Network – the portion of the network that carries a third of all road traffic and two thirds of freight traffic – in the period to 2040. Compared with petrol or diesel cars, EVs and PHEVs have high initial costs and low running costs. This is likely to incentivise their use for short journeys, such as commuting, rather than paying for public transport. Thus, a switch to electric could potentially add to congestion in cities at peak periods. This adds weight to the argument for widespread congestion charging as a means of taxing EVs as well as other vehicles. Implemented in a smart way, such a system could reduce congestion and make public transport more attractive on busy routes at peak times.

23) What should be done to reduce the demand for water and how quickly can this have effect?

150. The demand for water is made up of household use, non-household use and leakage, both within properties and within the suppliers' mains systems. Demand management is attractive as a means of adapting to water scarcity because it can be undertaken incrementally, without large up-front expenditure (in contrast to large capital-intensive water supply facilities), and can potentially be scaled up should that prove to be necessary in future.

Household use

151. The UK uses more water per capita than similar European countries such as the Netherlands and Germany. This is in part because of older water distribution assets (which leak more) and a relatively larger number of houses (i.e. fewer apartments).

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[47] An affordable transition to sustainable and secure energy from light vehicles in the UK, Energy Technologies Institute, 2013

[48] The transport congestion challenge, Royal Academy of Engineering, 2015

Notwithstanding these differences, reductions in water consumption per capita and in water leakage are both achievable. The increasing ambition in the water industry, regulators and government with respect to per capita consumption and leakage reduction is welcome. These two primary routes to saving water should proceed hand-in-hand, as water users will be less receptive to campaigns to reduce their water use if they are aware that significant volumes of water are being lost via leakage. Household demand is based on population, which is expected to grow significantly in the years ahead, increasing demand for water unless action is taken. Household use is dependent on the volume of water used by an appliance, the level of appliance ownership and frequency of use. The last two criteria are managed by householders. Their attitudes are subject to influence by the water companies and others to use less water.

152. Historically all houses paid for water based on rateable value. Now about 53% of households are metered with 'dumb' meters, read manually about twice a year[49]. Studies have shown that the incentive of now paying for water used has influenced behaviour and resulted in a drop in water used; average metered use is now about 125 litres per person per day, while non-metered use is about 155 litres per person per day[50]. Currently, water companies may only meter compulsorily in a water stressed area. With the Water UK long-term strategy showing transfer of water from the north west to the south east as being a viable water resources development long-term option, consideration should be given to water companies being able to meter compulsorily throughout the country. Smart metering would enable near continuous meter output. One long term possibility would be incentive tariffs but the social issues with these would need consideration.

153. Volume of water used by appliances per usage has, for many appliances, improved significantly over the last decade. However, more progress is needed. For instance, there are believed to still be about a million 13 litre flush toilets in use even when 4 – 2.5 litres dual flush are now in general use and 1.5 litre flush models are available. Mandatory water labelling will be important in supporting reduced water use in new homes and the important area of retrofitting existing homes. Evidence from energy labelling supports this approach and Waterwise are undertaking an independent review of water labelling to provide evidence to government as part of the Water Efficiency Strategy for the UK. Manufacturers should be encouraged to sell more efficient appliances and the Water Supply (Water Fittings) regulations could be tightened.

154. Since household water efficiency is set largely at the point of design and construction, household efficiency regulations should be made appreciably stricter. Part G of the Building regulations requires 125 litres per person per day but local authorities in areas of water stress can require 110 litres per person per day[51]. Several water companies are offering developers incentives (reduced or zero infrastructure charge) where they build to 110 litres per person per day or lower. The lower water use standard of 110 litres per person per day could be required across the country.

Water company leakage

155. Water company leakage reduced significantly in the first decade of privatisation. Since then the water industry in total has made little further progress in reducing leakage. Customers consider water company leakage to be wastage. Some water companies have appreciably higher unit leakage than others. This is partly because, as the water distribution ages, it naturally deteriorates and leaks more. It is also that most water companies consider they are at the economical level of leakage whereby the cost of finding and repairing the leaks is similar to the benefit in the water saved. However not all

[49] Delving into Water 2016, Table 6, Consumer Council for Water, 2016

[50] Delving into Water 2016, Table 9, Consumer Council for Water, 2016

[51] The consumption rates stipulated by Building Regulations are calculated using the water efficiency calculation set out in Appendix A of Part G of the Building Regulations: The Building Regulations 2010: Sanitation, hot water safety and water efficiency, HM Government, 2010

the benefits, such as reduced environmental impact, are included in the analysis. This needs to be addressed.

156. As above, enabled by smart metering, leak detection technology has now improved and should be encouraged. Ofwat has recently required water companies to reduce leakage by at least 15%[52]. This is to be applauded but should be monitored closely with a view to being reduced appreciably more in the following 5 year Asset Management Period.

Non-household use

157. Non-household use includes business, industry and agriculture. In UK businesses and industry, water cost is generally a very small proportion of annual turnover and thus little effort is generally made to reduce it. In Singapore where water is scarce, any new business or industry must demonstrate that it has the most water efficient system available. This approach should be considered as a requirement in the planning regulations as well as a requirement for established businesses in water scarcity zones. Compliance could be monitored by the normal water company waste inspectors.

24) What are the key factors that should be considered in taking decisions on new water supply infrastructure?

158. We presume that the question refers, not just to new water resources works such as reservoirs, but also to such works as water treatment works. Decisions on new supply infrastructure involve trade-offs in the water 'trilemma' which is analogous to the better-known energy trilemma; balancing security of supply, affordability and environmental impact. This balance is more complex for water because while water demand and supply is less variable in time than energy, it is more variable in space, because there is no national water 'grid' and water is much more energy-intensive to transmit than electricity or gas.

159. Decisions on new infrastructure should therefore explicitly consider the risks of water shortage, the costs of all options for addressing water supply-demand imbalances (including demand-side as well as supply-side interventions) and the need to safeguard sustainable quantities of water in the aquatic environment. Water infrastructure is very long-lived and, given the difficulty of predicting the need for water over such a long period, particularly with uncertain climate change impacts and demographic changes, the risk of creating stranded assets[53] needs to be minimised. All appraisal of major infrastructure decisions should fully consider these uncertainties. In addition, large infrastructure works are often difficult to phase economically, thus much of the cost of a new reservoir has to be committed in the initial phase. In contrast, an inter-regional transfer scheme can be built in stages as water demand does, or does not, increase.

160. A large-scale strategic approach needs to be developed. Since privatisation, planning arrangements in the water industry in England have been fragmented. This is now changing, with a recent national study by Water UK[54], the development of national modelling capabilities within the UK Infrastructure Transitions Research Consortium (ITRC), and regional water resources initiatives in the southeast and east of England. These strategic initiatives at regional and national scales are important because they enable the evaluation of risks of water scarcity at a national scale and the appraisal of the reliability of strategic infrastructure, like water transfers, and national policies. This national perspective also permits the evaluation of cross-sectoral interdependencies, notably between water and the energy sector.

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[52] Delivering Water 2020, Ofwat, 2017

[53] A past example of this is the Kielder Reservoir in Northumbria which was approved in the 1960s based on the heavy industry greatly expand its capacity (and hence its need for water) in the area. In the event, heavy industry declined rather than expanded leading to minimal use of the reservoir for water supply.

[54] Water resources long-term planning framework (2015-2065), Water UK, 2016

161. A systems view is needed of the whole water cycle, to address the following opportunities and challenges:

- Cross-sector collaboration: For example, this would be of benefit in reducing energy use by the water sector. Future solutions such as desalination, reuse of waste water and bulk transfers all have an energy use associated with them, and therefore integrated solutions that benefit both sectors will become increasingly valuable.
- Differing perspectives of the various stakeholders, including water companies, government, the regulators and customers.
- The need for environmental protection: The environment itself is a national asset, and the value of maintaining it in a clean, resilient state is an important consideration.
- The interactions between water supply and wastewater: Waste water can be viewed as a resource.

162. The UK Climate Change Risk Assessment showed that it is not only changes in weather patterns that will affect the amount of water available, but also the assumptions about how much water needs to be left within the environment, which suffers if too much is abstracted. Moves within government's 25 Year Environment Plan to put catchments at the heart of decision-making are welcome[55].

163. A national solution is required that accounts for regional and local variations in resilience, and provides a clear course of action for delivering long-term resilience. It should take into account the condition of assets, customer expectations, climate change and demographic change. It would also need to consider the structure of the industry, the role of the regulator and business planning cycles.

164. A national adaptive plan, recommended in a study on resilience by Water UK[56], would support ongoing water resource management plans and provide a broader view of requirements. This approach is different from existing water resource management plans, which are company specific. It would require cooperation between companies that are operating in a competitive market. There is more work needed in establishing how such a plan would function in practice, in particular, how the plan interplays with a company's own plans and how transfer and trading might fit in. This will need to be resolved by the companies themselves working alongside others in the water industry, the Environment Agency and Ofwat and has been considered in the draft water company Water Resources Management Plans currently with DEFRA.

165. Comparison of schemes needs to include viability, cost, effect of potential climate change, energy use, longer term effect on the environment, and public acceptability. For instance, effluent reuse schemes may have higher energy use, may result in less water during a dry spell in the water course to which the water was previously discharged, and a potentially increased 'yuck factor'. These factors are currently included in the assessment in the water company Water Resources Management Plans and must continue to be considered with the appropriate weighting dependent on society's attitude.

25) How can long-term plans for drainage and sewerage be put in place and what other priorities should be considered?

166. Future needs for drainage and sewage infrastructure are not well understood in the UK. While there have been significant improvements in asset management since privatisation of the water industry, there is not a consistent national database of sewerage assets. Sewer flooding is complex and highly localised, so is difficult (but not impossible) to analyse. Because of this, we do not have a 'big picture' view of the future needs for drainage infrastructure. Given the potentially significant costs involved in upgrading

[55] A Green Future, HM Government, 2018
[56] Water resources long-term planning framework (2015-2065), Water UK, 2016

drainage infrastructure to a sufficient standard, it is important that a national perspective on this issue is developed. This would help Ofwat to evaluate water companies' investment plans to improve sewer infrastructure. Long-term 25 year plans for water and sewerage should be approved by Ofwat as part of the Periodic Price Review process and updated every five years. Other drainage authorities should produce similar 25 year plans and seek government approval for them each Spending Review.

167. There has been very large investment in waste water treatment infrastructure to meet European environmental standards for inland and coastal waters, that in the past were regularly polluted with discharges of untreated sewage. The Thames Tideway project is the largest single instance of such an investment. There has been a tendency to centralise sewage treatment investments, which yields economies of scale. These economies of scale may change in future, particularly for new development, where international studies have demonstrated the benefits of decentralised facilities.

168. Most sewerage systems are so-called combined systems, where sewage and storm water are conveyed through the same pipes. This is an instance of regrettable lock-in, as most engineers would now accept that separate systems would be more desirable, so that sewer surcharging during extreme storms is not contaminated with untreated sewage, and so that sewage treatment works do not also have to deal with stormwater discharges. Nonetheless, reversing this technological lock-in would be exceptionally costly.

169. However, there is a need to review the design standard for drains and sewers to take into account more extreme rainfall storms in both intensity and duration over winter and summer. A standardised design methodology and a minimum standard for the UK for all drains and sewers that all drainage authorities, sewerage undertakers and private developers adhere to, enforced by statutory bodies, would also be a positive step. The design standard should consider future scenarios on climate change.

170. A key priority for the government should be to implement fully the provisions for sustainable drainage systems (SuDS) contained within the Flood and Water Management Act 2010. By helping to retain water above ground and slow the rate of runoff into sewers, SuDs can reduce the load on piped sewer infrastructure. SuDS also have landscape, habitat and water quality co-benefits. With good design they can readily be incorporated into new developments, adding to amenity value and the Adaptation Sub-Committee of the Committee on Climate Change has criticised the government's reluctance to introduce regulatory approaches that mandate SuDS.

171. It can be a challenge to retrofit SuDS into urban areas. However, the Chartered Institution of Water and Environmental Management (CIWEM) has produced recommendations for policy measures that would promote SuDS[57]. These better recognising and integrating the available benefits, beyond analysis solely on a flood management basis. Any development over 10 homes is required to integrate SuDS unless these are demonstrated to be inappropriate, however, this doesn't seem to act as an effective driver for recognising and properly integrating the various social, cultural and ecological benefits that can be realised as part of SuDS schemes. Clear guidance on best practices, for example on assessing multiple outcomes/benefits, would help with this.

26) What investment is needed to manage flood risk effectively over the next 10 to 30 years?

172. Flood risk management requires an integrated approach that combines measures to reduce runoff in catchments, engineered flood defences on rivers and the coast, 'grey' and 'green' urban drainage infrastructure, land use planning, measures to design and adapt buildings and infrastructure to be more resilient to flooding, flood forecasting, warning and evacuation, and insurance and other measures to promote recovery after

[57] A Place for SuDS, Chartered Institution for Water and Environmental Management (CIWEM), 2017

floods. The government recognises all of these interventions but is pursuing them with different degrees of vigour.

173. As with planning for water supplies, managing flood risk requires an adaptive approach that can cope with high levels of uncertainty. The Environment Agency's Long Term Investment Scenarios set out a range of scenarios and assumptions for optimising investment over the medium and longer term in England. These scenarios require updating to reflect growing understanding of flood risk and to explore optimal ways of responding to changing risk. There is also a need to conduct similar studies for the devolved administrations.

174. The management of risk can be broken down into five categories of action – reduce, eliminate, share, transfer, accept. Government policy should cover all five in explicit terms so that those at risk of flooding can see, for a particular location and for each type of flooding (fluvial, tidal, groundwater, surface water, pluvial, drainage/sewerage), who is accountable for each action, what the risks are and where they are located.

175. It is not efficient or rational to set a pre-determined target level of flood protection. That level should depend on the assets being protected and the cost of risk reduction. Evaluation of the benefits of risk reduction should take account of the wide implications of flood risk, including to infrastructure systems.

176. If not properly managed, the government's ambition to build large numbers of new houses could result in an increase in the number of properties exposed to flood risk. There is a tendency for developers to want to develop on flat ground because that reduces cost. Land in flood plains is often flat, however, it is important that development is not sited in flood plains wherever possible. For the time being, the land use planning system seems to be working quite well and the Environment Agency's advice is accepted in most cases. However, the suitability of the planning system may need to be reconsidered in the context of very large new developments, even if they are well protected, as they 'lock in' a commitment to continued flood protection in the future, which is likely to become increasingly costly in the context of a changing climate.

177. Mapping of the land to show where flooding is likely to occur is provided by the Environment Agency. However, in many instances house owners do not know that their houses are already at risk of flooding. It should be a requirement on solicitors acting for house purchasers to collect and provide this flood mapping. Local authorities should be required to inform all such householders with an encouragement to obtain and install flood protection measures such as removable barriers at doors and under floor air vents.

178. Since they underpin decision-making for flood resilience, weather forecasting and flood modelling should be improved to provide more reliable and timely flood forecasts. In terms of modelling:

- Accurate depiction of the spatial and temporal distribution of rainfall remains a key challenge and, added to this, climate change is causing phenomena which are not present in the observational record. Dealing with such uncertainty remains a key challenge.
- Cities are spatially large and, since buildings and a city's 'micro-features' substantially influence the extent of flooding experienced, it is important to achieve a high level of resolution within models
- Access to data can be a challenge, including working across administrative departments for better data access and assimilation. Wider application of the Open Data policy for real-time data would help.

179. While high quality data and flood modelling activities are a key activity, a critical issue is ensuring that results have a meaningful impact on decision-making across two main domains: urban planning and design, and flood preparedness and response.

180. There are various initiatives around the world that seek to test new approaches on flood risk management; for example, in 2013, China announced its 'sponge cities' drive. The central tenet of this initiative is that cities be designed to absorb, store and purify as much water as possible and release this water in a managed way that mitigates flood risk and maximises its utility. Other country-based initiatives include the Active, Beautiful, Clean Waters Programme (Singapore) and Water Sensitive Urban Design (Australia). In the UK there has been a focus on Sustainable Drainage Systems (SuDS).

181. There is a need to learn from international best practices and, in the UK specifically, to better understand the cost-benefit analysis of adaptation measures such as SuDS (see comments made in relation to this in response to Question 25). However, while much is being made about the benefits of natural infrastructure, such as afforestation, and, in general, these can reduce storm runoff in smaller floods, in reality the floods that cause the greatest impact on houses and infrastructure are the greater ones with longer return periods. During these floods the catchment is saturated and natural infrastructure can be of little, if any benefit. Before implementing natural infrastructure, stronger supporting documentation might be needed.

27) What would be the most effective institutional means to fulfil the different functions currently undertaken by the European Investment Bank if the UK loses access? Is a new institution needed? Or could an expansion of existing programmes achieve the same objectives?

182. Investment in infrastructure is capital intensive with long rates of return. The uncertainty around the nature of leaving the EU could potentially postpone investment decisions until the relationship becomes clearer.

183. The European Investment Bank (EIB), where the UK has a 16% shareholding, is a major source of infrastructure investment, investing €6.9 billion in the UK in 2016, with infrastructure projects accounting for 47% of this[58]. Shareholders in the EIB must be EU member states. Therefore, the likelihood is that the UK would have to relinquish its equity and role in making lending decisions. This would suggest that EIB finance for UK projects would decrease, but if the UK became a member of the European Free Trade Association (EFTA) it would be eligible for access to the EIB's EFTA Loan Facility[59].

184. The scale of the EIB is often missed; it is the largest multilateral bank in the world by a very large margin. If the UK were to lose access to the EIB, there is no other existing institution that would take its place. There are no other programs in place in the UK that would, in the foreseeable future, be able to match the scale of the EIB investment in infrastructure finance in the UK; the historic scale of lending to, for example, water companies or National Grid, would be hard to match.

185. The EIB is effective in low-cost lending into infrastructure partly because of its own low cost of finance (which could itself be damaged by the UK's exit) but also all the benefit of its own low cost of borrowing as a non-profit making institution with a very strong, diverse capital base.

186. Replicating the EIB within the UK would be extremely difficult. Any new institution would suffer from materially worse risk concentration than the EIB. The new institution will need an extremely significant capital base and a cadre of professional infrastructure lenders from a multilateral background and a benign approach to state aid and banking regulation for at least 10 years while the new institution established itself. Such a process would thus take time and a significant amount of public capital and it is likely that any UK-specific replacement would be materially less effective in terms of its impact on the national economy.

[58] The EIB in the United Kingdom, European Investment Bank, 2018
[59] The European Free Trade Association, European Investment Bank, 2018

187. Given these considerations, the UK should be making every effort to work with the EIB as part of the Brexit process to establish a mechanism by which it could stay a member and beneficiary of the EIB but under a different set of rules.

28) How could a comprehensive analysis of the costs and benefits of private and public financing models for publicly funded infrastructure be undertaken? Where might there be new opportunities for privately financed models to improve delivery?

188. The response to Question 4 referred to the challenges involved in defining the criteria for success within CBA, beyond an acceptable threshold for a benefit/cost ratio for a specific project. Financing models for infrastructure need to be tailored to individual projects, the specific benefits they will provide and the local context. This suggests that a broad view of possible financing models should be adopted during the initial scoping phases for national infrastructure, rather than seeking to perform an evaluation of the strengths and weakness of any one financing approach in advance.

189. Regarding service delivery, whether privately or publicly financed, there may be opportunities in either vertical (for example, within a single local authority, county council or municipal authority) or horizontal (across different local authorities) bundling of service delivery to achieve efficiencies such as in back office resources and rarely needed equipment.