Technologies for clean growth

A cross-engineering sector response to the Science and Technology Committee inquiry on Technologies for meeting Clean Growth emissions reductions targets on behalf of the following organisations:

Royal Academy of Engineering

Chartered Institute of Building Services Engineers

Energy Institute

Institution of Chemical Engineers

Institution of Engineering and Technology

Institution of Gas Engineers and Managers

Institution of Mechanical Engineers

November 2018

Summary

1. With current policies, the UK is not on course to meet its 2050 emissions target set out by the Climate Change Act. Bold action is required to stay on trajectory and deliver the objective in a secure and affordable manner.

2. In all energy policy, a whole system approach that includes technological, governance, regulatory, business, and consumer elements, is vital to understand the full implications of any new technology.

   Across sectors, many of the technologies needed to decarbonise by 2050 already exist:

   2.1 Innovative policy making that works to break down silos and drives large-scale deployment of existing low-carbon solutions is more urgent than support for the development of new technologies.

   2.2 Government should establish local, whole-system, large-scale pilot projects to establish how technologies, consumer behaviour, and financial mechanisms can be integrated together in real-world situations to deliver low carbon energy provision at lowest cost.

3. Considering the whole system, common areas that require a greater policy focus include:

   3.1 Demand side reductions – while new technology will play an important role in delivering emissions reductions targets, demand reductions and management will be critical and need to be more fully integrated into the government's strategy.

   3.2 Digital technologies - high quality data coupled with advanced analytics and smart networks will play a crucial role in meeting emissions targets by enabling greater innovation and utilisation of all available technologies. In realising these opportunities, due consideration must be given to system security and resilience, data governance and consumer protection.

4. Since the introduction of the Climate Change Act, greatest progress has been made in the decarbonisation of the power system. While this needs continuing attention, particularly given the likely shift to electricity in transport and heating, there is now a need for much greater focus on decarbonising heat (and the built environment and industrial processes) and transport.

5. Heat:

   5.1 The decarbonisation of heat will look different to the decarbonisation of the power system and must take into account the scale of change required, the seasonal and daily pattern of demand, and the role of the consumer in the system.

   5.2 Demand reduction in buildings and energy efficiency should be fully integrated into the government's strategy for meeting emissions targets. There is a particularly urgent need for government to create a framework to drive the retrofit of the existing UK building stock.

5.3 Large-scale demonstration and roll out projects should be prioritised to explore how various heat technologies can be scaled up to provide resilient change to heating at lowest cost.

5.4 Significant government support is likely to be required to drive the deployment of new technologies for heating, including the deployment at scale of proven low carbon heating technologies such as district heat networks, heat pumps, heat recovery and micro-CHP, and work with the gas industry on the decarbonisation of the gas grid.

6. Transport:

6.1 Demand reduction in the transport sector should be fully integrated into government strategy, with a strong focus on behavioural change and modal shift.

6.2 Government should accelerate the uptake of battery electric vehicles and plug in hybrid vehicles, particularly by accelerating the roll-out of charging infrastructure, in both urban and rural areas, through ensuring local authorities take up government funding schemes, and providing incentives to support installation of charging grids outside cities.

6.3 Greater government support is required for the development and deployment of alternative fuels for heavy duty freight, aviation and shipping, that may include low carbon footprint liquid fuels, LNG, CNG, decarbonised gas and fuel cells.

7. As highlighted in the recent IPCC report[1], the action required to limit temperature rises to 1.5°C is dramatic, and makes the steps taken so far look small. UK Government strategy should consider the international context, continuing to take leadership in highlighting and seeking solutions to this major systemic global issue. Strategy should seek to address the twin challenges of tackling climate change and providing increased supplies of affordable low carbon energy to developing world economies, which represents a significant global market opportunity for UK companies.

Introduction

8. We welcome the opportunity to respond to this call for evidence to the Science and Technology Committee on Technologies for meeting Clean Growth emissions reduction targets. This is a cross-engineering sector response, developed by the organisations listed below – an example of the increasing collaboration between engineering institutions as the sector works towards the establishment of the Engineering Policy Centre in 2019:

   Royal Academy of Engineering

   Chartered Institute of Building Services Engineers

   Energy Institute

   Institution of Chemical Engineers

   Institution of Engineering and Technology

[1] Global warming of 1.5°C. Intergovernmental Panel on Climate Change. October 2018.

Institution of Gas Engineers and Managers

Institution of Mechanical Engineers

9. With current policies, the UK is not on course to meet its 2050 emissions commitment set by the Climate Change Act. Bold action is required to stay on trajectory and deliver the objective in a secure and affordable manner. It is important to remember that greenhouse gases are cumulative and therefore a timely response is essential. The slower the response and deployment of clean technologies, the more emissions are released and the steeper and more severe the correction path required.

10. The Clean Growth Strategy recognises the impressive emissions reductions already achieved in the UK, but these have been delivered by the easiest changes in technologies and behaviour. Deeper cuts will be progressively harder and affect many more people. Many will require greater intervention by government. Reductions to date have also not taken into account carbon embedded in imported goods and services. Government should find ways to incentivise carbon reduction in these products and, where possible, show leadership in this area internationally. Solutions are possible that build on progress, but the scale of the challenge should not be underestimated.

Whole system thinking

11. In all energy and transport policy, the implications for the whole system must be considered.

12. The whole energy system includes all contributing physical, data, policy, commercial, corporate, financial, regulatory, societal, health and safety, skills and behavioural elements from the point of sourcing energy from the natural environment to the point of its end use in individual energy consuming devices.

13. This includes all physical energy systems - electricity, built environment, transport, industrial sectors and agriculture. It must include both supply and demand sides and full life cycle assessments from inception through to disposal, de-commissioning, or re-use or re-absorption into the natural environment, seeking to develop and implement opportunities for greater resource productivity and ultimately a circular economy, and be considered nationally and internationally. Equally important are how institutional systems, including government strategy and regulation, business models, and the behaviour of end users, interact with physical systems. Interfaces with other systems, for example with the water system, healthcare, and broader environment, should also be considered.

14. It can be useful to consider subsystems of the whole for particular purposes. However, these need to be treated very carefully and their limitations understood, to avoid missing important interactions which can have major effects on the wider system's behaviour (see box).

Thinking through energy issues can lead to radically different conclusions if system boundaries are taken in the wrong places. As an example, recent policy interest in electrification of domestic heating implies very large increases in peak electricity demand to replace the flexibility we enjoy currently from the gas system. However, embracing the potential for thermal energy storage and delivering cost effective demand reductions through improved building energy efficiency could mitigate this substantially. Going further, a decarbonised gas grid or hybrid gas/electric systems could potentially allow home heating to continue to be delivered more affordably than electric options. However, decarbonising the gas grid to hydrogen fuel has further implications regarding how hydrogen is sourced. It could be made using electrolysis of water, were surplus renewable energy available and, in the process, create options for large scale energy storage as hydrogen, and/or could be made as part of carbon capture from fossil fuels, implying perhaps a greater ongoing role for fossil fuels in a decarbonised energy system than would otherwise have been the case. The point being that too limited a consideration of the system would exclude potentially important ways forward, causing much higher costs to consumers than need be the case.

15. The digitisation of energy supply to customers is creating opportunities for consumers or their digital assistants to make choices to improve consumer experience and value, and at the same time allowing services to be provided to the energy system from mass distributed devices, such as connected appliances or electric vehicles, in entirely new and more cost-effective ways. Considering the implications of how physical, data, market, regulatory, policy and commercial elements interact will be essential to ensure digital systems do not create emergent behaviours that are unpredicted, uncontrolled, or would likely result in large costs or risks. For example, the consequences of switching the chargers of a large distributed electric vehicle fleet on or off in response to a price signal could have major implications for overall system stability, and localised system behaviour.

16. One important system consideration is the capacity of existing infrastructure, as well as industry and supply chain capacity to deliver solutions, once policy direction is set. A long-term, national, and stable programme of government support is needed to give industry the confidence to invest in their internal capacity and build the energy infrastructure needed to transition to a low carbon future.

Implications of whole systems approach

17. A comprehensive review of incentives and regulations is required. Innovative policy making that works to break down silos and drives large-scale deployment of existing low-carbon solutions is more urgent than policy focused on the development of new technologies. There is a need to ensure government strategies, market incentives and regulatory requirements are aligned across the whole system, and don’t have unintended consequences in other sectors.

18. In most sectors, the technologies needed to decarbonise by 2050 already broadly exist or are under development. What is not understood is how to deploy the right combination of technologies to deliver the full range of services in a functional and cost-effective way. Government should establish local, whole-system, large-scale pilot projects to establish how technologies, consumer behaviour, and financial mechanisms can be integrated together in real-world situations. Such pilot schemes would allow robust integrated systems analysis to be undertaken through monitoring and testing of innovative combinations of technologies, business models, and user behaviour, and provide a basis for learning by doing. This would accelerate the understanding of the

advantages and disadvantages under real conditions that are governed by consumer and user behaviour. The ISCF programme *Prospering from the energy revolution*[2] is a positive initiative towards whole energy system demonstrations that needs to be supported and built on, in particular to include the demand side of the system.

19. Energy system transition will require significant changes to the engineering approaches, codes, standards, modelling tools, and associated regulatory and economic structures across many areas of the system. A long-term view of energy transition is required, and government and the sector must work closely together to implement the required changes.

Demand side

20. **Action to fully integrate the demand side of the energy system into the government's strategy will be critical to meeting climate change targets.**

21. Demand reduction is often a 'no regrets' scenario. In many cases, it reduces both direct costs to consumers, and costs to other system actors which are ultimately paid by consumers, as well as lowering emissions of greenhouse gases and aiding security of supply.

22. Demand can be reduced by various methods including greater energy efficiency in appliances, processes, or the built environment, automation through Internet of Things, or changes in consumer behaviour. However, there can be financial and non-financial barriers for consumers and businesses accessing these demand reduction mechanisms. Policy to drive demand reduction, including incentives and regulation, should be integrated into energy policy in all sectors, including heat and transport (see sections below for more details). In terms of industrial processes and efficiency, greater government incentives are needed to enable companies to invest in larger, longer-term efficiency projects that may have the largest impact on carbon emissions, since companies may lack sufficient market certainty to invest in such long-term projects.

23. In setting policies to encourage demand side reduction and efficiencies, full life-cycle emissions must be taken into account across the whole chain in all regions (UK and international) to ensure carbon emissions are not simply moved abroad to competitor countries where the relative emissions might be even higher.

24. The potential impact of digital technologies such as AI and the smart grid to improve efficiency while delivering user requirements is significant. Regular focused review is required to determine appropriate policy, research, infrastructure and deployment support in this area. There is a need to understand consumer incentives and behaviour in relation to this; access to high quality and ideally open or sharable data will support this.

25. Changes in behaviour of end-users can lower demand and increase system flexibility through demand management. Greater understanding of consumer behaviour and their engagement with technology is urgently needed to understand these implications, through studies such as the recent work by Octopus Energy[3]. This is particularly the case in the heat and transport sectors where changes will only have a material effect on

[2] Innovate UK. Prospering from the energy revolution. https://www.gov.uk/government/news/prospering-from-the-energy-revolution-full-programme-details. Accessed 10/2018

[3] Agile Octopus: A consumer-led shift to a low carbon future. Octopus Energy. 2018.

the system with the participation of large numbers of individuals. This will require an appreciation of the full range of different end users and what they value in the delivery of energy or services, taking into consideration the context and framing of the opportunity, the characteristics of new technologies and how they will be used, and the impact of government policies on deployment of new technologies or energy efficiency measures.

26. The behaviour of the businesses and industries that deliver products and services are equally important. Rapid innovation and disruptive business models in certain parts of the sector are now competing against more traditional incumbent players. As such, there is a need to remove institutional barriers and silos across government, particularly across sector regulators. Impacts on social equity must also be considered in any new policy or market structures.

27. How demand side measures play out in real-world situations can be complex. For example, post-retrofit energy usage will often be higher than predicted as a result of poor design, installation and usage as well as a small amount of increased use because of greater affordability. Large-scale pilots and roll out projects (as noted above) should be prioritised to explore the scale-up and combination of various technologies and policy measures to provide resilient demand reduction at least cost.

Digital and data

28. **Digital technologies, such as AI and the smart grid, will play a crucial role in meeting emissions targets by enabling greater innovation and utilisation of all available technologies, increasing the flexibility, interoperability and optimisation of the whole system and enabling all parties to play a part in energy markets. In realising these opportunities, due consideration must be given to system security and resilience, access to high quality data, data governance and consumer protection.**

29. There is an increasing ability to collect large quantities of useful data from sensors, the Internet of Things and consumers, and to analyse this data through advanced analytics and machine learning. Data will contribute to achieving convergence across different energy networks, allowing greater interoperability and flexibility in the future, and hence potentially better services and lower costs to consumers. Data will also be needed to understand and manage the operation of new types of distributed energy generation, including community energy systems and heat networks.

30. The successful operation of the smart grid in the future will be underpinned by the availability of real-time data, as the electricity grid, particularly at the distribution level, moves from one-way to two-way flow and energy networks in general become more integrated, leading to more integrated and complex transmission, distribution and trading. More data will be needed to optimise decision-making for operation and investment planning. In particular, systems will be required that integrate processes to enable long-term planning, day/hour ahead forecasting and immediate operational management.

31. A significant source of the data will be personal data from consumers or businesses collected via smart meters or other methods. Much more work will be required to understand the value proposition and incentives to share this data, develop effective technologies and governance structures to curate and distribute the data and build trust that personal data will be secure and benefits shared equally.

32. If the necessary processes can be put in place to collect, curate and share data, there will be huge opportunities to drive innovation in the energy sector, leading to new products and services that could accelerate decarbonisation, open-up new business opportunities and hence support clean growth. Renewable generation, energy storage, demand management, mobility, smart appliances and other emerging technologies will all benefit from digital innovations that increase efficiency and deliver better consumer services. However, digital innovations can also have a disruptive effect and government should track potential system-wide impacts and unintended consequences. The IET/Energy Systems Catapult Future Power Systems Architecture Project has explored these issues in some detail[4].

33. The increasing integration of digital and physical parts of the energy system, while affording many opportunities, also creates added risks to both the safety and resilience of the system. The energy industry needs to understand the potential cybersecurity risks that can be introduced through advanced digital technologies and increased connectivity, and mitigate those risks by following current best practice guidelines provided by agencies such as the NCSC.

34. Government also needs to be aware of the growing dependence of society on the energy system. Any significant loss of supply could have major social and economic consequences. Resilience, the ability to withstand and recover from incidents, is critical for the energy system along with contingency plans that take account of the present-day reliance on digital communications. This area seems under explored at present and the experiential evidence of systems thinking in resilience is not encouraging[5].

Heat, Cooling and Built Environment

35. **Decarbonising heating systems, particularly home heating systems, must be a priority for UK energy policy. There is no possibility that the UK could meet its 2050 carbon emission commitment without a fundamental change to the way homes are heated[6], and existing UK policy will not deliver this transformation.**

36. Heat represents roughly one-third of the UK's total greenhouse gas emissions, and the decarbonisation of heat is regarded as one of the toughest challenges in the transition to a low-carbon future. Decarbonisation of cooling is also becoming increasingly important, both in air conditioning and the cold chain. There is an urgent need for a concerted policy focus in this area, covering R&D, infrastructure systems, market development, regulation and consumer behaviour, similar to the aligned policy that has supported the development of the renewable power sector in recent years.

37. **Heat is different from power on account of the scale of change required, the seasonal and daily pattern of demand, and the role of the consumer in the system.** A recent briefing note from the UK Energy Research Centre (UKERC) considered energy demands during the 'Beast from the East' cold weather period in early 2018, and found that demand for local gas peaked at 214GW compared to 53GW demand for power. The steepest rise in local gas demand was 116GW over three hours,

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[4] The Future Power System Architecture Project, https://www.theiet.org/sectors/energy/resources/fpsa/index.cfm?origin=reportdocs. Accessed 10/2018.

[5] Living without electricity. Royal Academy of Engineering. 2016. https://www.raeng.org.uk/publications/reports/living-without-electricity

[6] Heat: degrees of comfort? Royal Academy of Engineering. 2012. https://www.raeng.org.uk/publications/reports/heat-degrees-of-comfort.

compared to the steepest rise in power demand of just 16GW[7]. It is essential that the transition to an alternative heating system fully considers the nature of heating requirements and demand.

38. As outlined more fully above, demand reduction should be fully integrated into the government's strategy for meeting emissions targets. Particularly key to heat, building regulations (and their enforcement) should be strengthened to ensure new buildings are designed, constructed and operated to the highest feasible operational performance and energy efficiency standards, and that refurbishment of existing buildings is leveraged to enhance their efficiency. Every home that is built to lower standards locks the occupants into excessive energy demands and costs that last for decades, and hampers efforts to meet climate change targets. However, most of the buildings that will exist in 2050 have already been built. The knowledge to improve the existing housing stock already exists, but there is an urgent need for government to create a framework to drive the retrofit of existing UK building stock on a national scale, using regulatory or policy incentives. The opportunity for the public sector to show leadership using its own estate should not be underestimated; this will also facilitate the development of supply chain skills.

39. Addressing the challenges related to decarbonisation of gas and heat, the Committee on Climate Change has identified multiple potential decarbonisation pathways for low-carbon heating[8]. Alongside demand reduction and local heating pathways, three potential central technology pathways were identified:
    - 39.1 'greening' the gas supply by shifting to low-carbon gases such as hydrogen, biomethane and BioSNG.
    - 39.2 electrification of the heating sector supported by low-carbon power generation.
    - 39.3 hybrid solutions, described by the WWU Freedom Project[9], with the bulk of heat demand met by electricity, and peak demands met by green gas. This pathway is based on combining the use of gas and electric heating systems, for example using hybrid heat pumps.

40. A recent Imperial College report[10] concluded that there are still multiple possible routes for achieving the decarbonisation of heat, and it is not yet possible to select an optimal path due to uncertainties in the system. For example, the cost and impact of electrification would depend strongly on progress with decarbonisation in the power sector, while the implications of replacing natural gas with hydrogen may depend upon the development of CCS at scale.

41. Therefore, the focus of action should be to address uncertainties and take an integrated systems approach. As recommended above, large-scale demonstration and roll out projects should be prioritised to explore how various technologies can be scaled up and combined with demand reduction policies to provide resilient change to heating at lowest cost. These initiatives should be designed to encompass all aspects of technology

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[7] Challenges for the decarbonisation of heat: the scale of local gas demand vs electricity supply in Winter 2017/2018. Wilson et al 2018. UKERC. http://www.ukerc.ac.uk/news/gas-consumption-during-beast-from-the-east.html Accessed 10/2018.
[8] Next steps for UK heat policy. 2016. Committee on Climate Change
[9] Western Power Distribution. Flexible Residential Energy Efficiency Demand Optimisation and Management https://www.westernpower.co.uk/projects/freedom Accessed 10/2018.
[10] Analysis of alternative UK heat decarbonisation pathways: For the Committee on Climate Change. Imperial College London. 2018. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/

development and deployment including training, real-world evaluation, data sharing, and longitudinal assessments of customer behaviour and engagement.

42. **Significant government support is also likely to be required to drive the deployment of new technologies for heating, including the deployment at scale of proven low carbon heating technologies such as district heat networks, heat pumps, heat recovery and micro-CHP, and, working with the gas industry, decarbonisation of the gas grid.** This should take the form of aligned R&D, policy, regulatory, and market change, including for policy focus for system change in this area.

43. A systems architect for heat would also be valuable. Government should support a Future Gas System Architecture which will adopt a 'systems engineering' approach to look at the gas system as a whole, or at least on a substantial regional sub-system basis, using the same methodology as the Future Power System Architecture (FPSA)[11] project carried out by the Department of Energy & Climate Change, the Institution of Engineering and Technology and the Energy Systems Catapult, so that the two pieces of work may complement each other and move the UK one step closer to a whole system approach to energy.

Accelerating the Shift to Low Carbon Transport

44. **Changes to our transport system offer enormous potential for accelerated decarbonisation to assist the UK in meeting future carbon budgets. Enabling these changes should be a priority for the Government as part of the implementation of the Clean Growth Strategy.** Accelerating the decarbonisation of transport will likely also have significant benefits for urban air quality and related health considerations, and these aspects should be incorporated as part of a whole-systems approach to policymaking.

45. Carbon emissions from transport in the UK have remained broadly static since 1990 and even rose slightly in 2016. Transport is now the largest contributor to UK carbon emissions, comprising 34% of the total.[12] In road transport, which makes up the largest proportion of the sector's emissions, improvements in vehicle efficiency have been offset by an increase in road miles.[13]

46. New technologies and improvements in existing technology will be important but, as for other sectors, **there should also be a strong policy focus on behavioural change and modal shift**. Incentivising people, where possible, to give up their cars for walking, bicycles or public transport will result in larger emissions cuts per person than getting them to purchase a new vehicle, even if it is electric.

47. Provision of accurate information to consumers is essential to enable them to make appropriate choices. Digital planning technologies enable people to take advantage of modal shift opportunities. These services are typically better in urban areas, so we

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[11] Future Power Systems Architecture. https://www.theiet.org/sectors/energy/resources/fpsa/index.cfm?origin=reportdocs Accessed 10/2018.

[12] 2017 UK Greenhouse Gas Emissions, Provisional Figures. Office for National Statistics. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695930/2017_Provisional_Emissions_statistics_2.pdf Accessed 10/2018.

[13] Road Traffic Statistics. Great Britain 2017. Office for National Statistics. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741953/road-traffic-estimates-in-great-britain-2017.pdf Accessed 10/2018.

should strive to ensure the rural population also have the information they need to inform lower carbon travel decisions.

48. Urban planning and technology can also play a role in allowing people to travel less, considering changing engagement of consumers with work, retail, leisure and health. Broadband internet, smartphones and cloud computing are now commonplace, which makes working from home possible for millions of people in the UK.[14] Working with business to enable more people to work from home and avoid commuting will reduce road and rail miles, which could both save energy and alleviate stresses on the transport system. However, this could also have the effect of increasing built environment emissions when homes are heated more often through the working day – an example of the whole system impacts that need to be considered.

49. Modal shift can only go so far, however, and many people will continue to want or need to own their own vehicle. One key technology for the decarbonisation of light road transport is battery electric vehicles (BEVs) and plug-in hybrid vehicles. The uptake of these has begun to accelerate, but is starting from a very low base. In order to enable further uptake, the Government should use the powers gained through the recently passed Automated and Electric Vehicle Act[15] to remove the mental barrier of 'range anxiety' that prevents many people from switching from a diesel/petrol car to a BEV.

50. **Government must accelerate the roll-out of charging infrastructure, in both urban and rural areas**, through ensuring local authorities take up government funding schemes, and providing incentives to support installation of charging grids outside cities. A new market structure should be developed to support consumer access, including ensuring greater technical and business model interoperability between operators, such that consumers can charge at most or all points.

51. Whole system considerations across Government will be essential for the successful deployment of electric vehicles. The switch to electric vehicles will place increasing demands on the power system, but also offers opportunities to use vehicle batteries for demand management and storage for the electrical grid. Decarbonisation of transport should also go hand in hand with the drive to reduce pollution from our urban areas. Regulatory and policy silos can currently act as a barrier for whole system policymaking in this field.

52. As the light road fleet becomes electrified, tailpipe emissions will become less relevant. The whole life cycle emissions associated with road travel will need to be taken into account when developing policy. This includes the emissions associated with electricity generation directly and the embedded emissions that result from the manufacture, non-fuel use, and end of life disposal of the vehicles and batteries.

53. As batteries have a relatively low power density and long charging time, battery electric heavy duty freight is unlikely to be feasible. Government support for the large-scale testing, evaluation and deployment of alternative technologies such as liquefied natural gas (LNG), compressed natural gas (CNG), decarbonised gas, hydrogen fuel cells, or combined pantograph and battery technology for heavy duty freight should be a priority.

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[14] Homeworking: helping businesses cut costs and reduce their carbon footprint. Carbon Trust. 2014. https://www.carbontrust.com/resources/reports/advice/homeworking-helping-businesses-cut-costs-and-reduce-their-carbon-footprint/

[15] https://services.parliament.uk/bills/2017-19/automatedandelectricvehicles.html Accessed 10/2018.

54. As for the light fleet, all emissions associated with heavy goods vehicles (HGVs) should increasingly be taken into account, including those from on-board auxiliary power units. There is also a continued role for heavy freight management and logistics to be improved to contribute to emissions reductions.

55. Shipping and aviation are likely to be significantly more difficult that road freight to decarbonise. Alternative fuels, such as synthetic fuels, are likely to play a greater role here, and again collaboration between government and industry to support the development and deployment of these technologies will be key.

56. Despite much enthusiasm for electric vehicles, it must be remembered that the internal combustion engine is not going to disappear immediately. Especially for larger vehicles like HGVs and ships, it will be many years before suitable alternatives have an impact. There is still room for increases in efficiency of conventionally fuelled vehicles, which should be supported through continued R&D and policy incentives. Low cost short-term gains in both air quality and carbon emissions could be achieved through incentivising the uptake of vehicles that meet Euro 6 standards, for example through targeted scrappage schemes and more stringent random vehicle testing to take the worst polluting vehicles off the road.

57. With regard to our railway system, further electrification of the network is likely to offer the best immediate potential for decarbonisation and this should take place through a national rolling programme to prevent the excess costs associated with the stop-start approach which the UK has seen in recent decades. Battery power, hydrogen and LNG could play a role in replacing diesel powered trains, particularly in parts of the network that are difficult to electrify.

Power system

58. Since the introduction of the UK Climate Change Act, decarbonisation of the power system has received greater policy focus than heat and transport systems and has made greater progress as a result. However, with potential shifts to large scale electrification in heat and transport systems, the power system will need to handle much larger quantities of energy going forward.

59. Additionally, decarbonisation of the power system will generate a number of systems challenges that will require significant changes to engineering approaches, models, standards, and codes of practice, and there is a need for this transition to be planned and managed. For example, increasing the proportion of renewable electricity generation will reduce the inertia and short circuit level characteristics currently provided by our largely AC synchronous electricity generation sources. This transition will therefore need to be accompanied by widespread changes in models and standards to ensure stability of supply in a very different power system. These challenges are increasingly recognised in the National Grid Electricity Transmission's System Operability Framework forecasts. However, successful transition will require close working between government and industry, with a longer-term view of power system transition.

60. Part of the long-term future of the power system is likely to be increasing levels of decentralisation including distributed generation, energy storage, demand management and smart systems. Much of this will be developed or controlled by non-incumbent market actors, including small companies, consumers, and large companies currently operating in other sectors. There is a need to consider how this will impact on technical

aspects of the grid as well as market frameworks and business models, including impact on the consumer and equity across society.

61. As outlined, heat and transport are the two sectors where progress to decarbonise is most needed. However, decarbonisation of the power grid cannot be taken for granted. Carbon capture, usage and storage (CCUS) and nuclear power are both critical technologies that are failing to deliver as expected, but for different reasons.
    - 60.1 Government must work with industry to support the development and deployment of CCUS in the UK where cost effective, particularly facilitating the development of relevant infrastructure and appropriate market frameworks. In addition, development and deployment of CCUS in industrial processes such as in the steel and cement industries must be reviewed and supported as this will be essential to meet global emissions targets. The latest IPCC report has highlighted that 'negative emissions' are an essential element of almost all plausible pathways to limit global average temperature growth to 1.5^{o}C[16]. A recent Royal Academy of Engineering and Royal Society report found that CCS infrastructure will be an important component of any suite of negative emissions technologies[17]. As such, the global market for CCUS could become a major opportunity for UK-developed technology and capability.
    - 60.2 Greater concerted policy action is required if the UK is to develop and deploy next generation nuclear power, including the development of a clear market framework, regulatory support, and R&D funding.
    - 60.3 An open dialogue with emergent sectors should be continued to establish the necessary types of support to bring these sectors to market maturity e.g. the tidal generation, demand management and storage sectors.

International context

62. Finally, it is worth reiterating that UK clean growth policy should not just be a policy for decarbonising UK energy usage, but also needs to identify opportunities for UK wider economic growth, especially those that can contribute to the global challenges of climate change and meeting the UN Sustainable Development Goals.

63. In this context, there are currently 4.5 billion people globally living on less than $8 per day whose lives will only be improved by economic growth that is relatively energy-intensive, as they industrialise, urbanise and increase consumption. Of course, it would be valuable to find less energy intensive pathways to prosperity, but much more likely to succeed is to provide more and cheaper access to reliable low-carbon energy and transport solutions. This represents a major opportunity for the development of new technologies and new business models that should be more clearly integrated into the UK clean growth strategy. Though some may evolve because the UK market itself first deploys that solution, many more will need to be designed and developed with developing world challenges and consumers in mind from the outset. Much more could be done to encourage and support UK researchers and innovators to pursue such opportunities within a UK clean growth strategy that is truly "outward-looking".

[16] Global warming of 1.5^{o}C. Intergovernmental Panel on Climate Change. October 2018.
[17] Greenhouse gas removal. The Royal Society and the Royal Academy of Engineering. 2018.