Written evidence submitted by the
Centre for Research into Energy Demand Solutions (CGE0070)

Introduction

1. This submission is from the Centre for Research into Energy Demand Solutions (CREDS). CREDS is a major initiative of the Energy Programme of UK Research and Innovation. It is a distributed centre, involving 13 universities, with a core team based at the University of Oxford. It began in April 2018 and will run to March 2023, with a budget of £19.5 million. More information is on the website: creds.ac.uk.
2. The submission has been prepared by the CREDS Director Nick Eyre (University of Oxford) with input from Co-Directors Tadj Oreszczyn and Robert Lowe (University College London), Jillian Anable and John Barrett (University of Leeds), Jacopo Torriti (University of Reading).
3. We have no relevant interests to declare.
4. Our summary assessment of key technologies and other related issues is provided below. We would be happy to provide more detail and/or oral evidence to the Committee.

Executive summary

5. Improvements in the energy efficiency of end use technologies have been critical to delivering UK energy policy objectives. This will remain true as there is substantial scope for further improvement, especially as electricity substitutes for direct use of fossil fuels. Continued innovation and deployment are required across all the main energy using sectors: buildings, transport and industry.
6. However, energy efficiency improvement is not the only challenge. Electricity use will need to become more flexible in time to accommodate rising levels of variable electricity generation. Fuels will need to be decarbonised at the point of end use, either through use of electricity or alternative vectors such as hydrogen. In either case, new end use technologies are critical.
7. Innovation in energy demand is key to delivering the goals of the Clean Growth Strategy, but this needs to be interpreted broadly to include changes in systems that drive energy demand, such as changes to demand for energy intensive materials and switching between different transport modes. Social change and technical change are strongly linked. Business models, supply chain skills, user practices and policy frameworks can constrain or drive technology improvement and deployment.

Key energy efficiency technologies

8. UK primary energy demand has not only been decoupled from economic growth, it has fallen in absolute terms, by about 20% since 2003. This decoupling of energy demand from economic growth has contributed more carbon emissions reduction than the combined effects of the UK's programmes in nuclear, renewable and gas fired power generation.

9. Changes in energy intensity and energy use has been driven by two factors: economic restructuring (away from energy intensive manufacturing and towards services) and technical energy efficiency improvement (Hardt et al, 2018). The technical improvement has been achieved through deployment of more efficient technologies and user practices across the economy.

10. International evidence shows that as new efficient technology is deployed, technical innovation has created new potential at a broadly similar rate (NAS, 2010; IPCC 2014). In general, mass market energy efficiency technologies can be deployed faster than large scale supply side changes. For example, household lighting technologies will go through two major transitions (incandescent to fluorescent to LED) in the UK on about the same timescale as the construction of one nuclear power station. There are thermodynamic limits to energy efficiency, but best estimates indicate that there is potential for a further six-fold improvement (Cullen and Allwood, 2010; Cullen et al, 2011).

11. Energy efficiency improvement in homes and businesses leads directly to increased energy productivity. It is therefore **not** just an environmental imperative, but also productive investment, creating employment, supporting competitiveness and contributing to an innovative economy. Supporting energy efficiency should therefore be seen as an essential part of UK industrial strategy. There are other potential benefits, for example in cleaner air, more comfortable buildings, less waste and more liveable urban environments.

12. In summary energy efficiency supports all three pillars of the so-called energy trilemma – security, affordability and greenhouse gas emissions reductions. The Clean Growth Strategy cannot be delivered without substantial energy efficiency technology investment.

Key Energy Efficiency Technologies

13. Energy efficiency technology is inevitably a complex topic, as energy provides multiple services across society, and therefore there are multiple end use technologies. However, there are three broad sectors: buildings, transport and industry, in which some priorities can be identified.

14. In UK buildings, the largest single use of energy is space heating, followed by water heating, lighting, cooking and electrical appliances. The only growing energy use is for information technology and entertainment. Space heating is the dominant energy use in most buildings. It can be reduced by improving the efficiency of energy conversion to heat and/or the heat retaining properties of the building. In the former category, boilers are reaching the limits of their potential efficiency, but there is significant scope with newer technologies such as heat pumps (see below). Improving the performance of building envelopes requires attention to thermal insulation and ventilation. Both can be addressed more easily at the point of construction and new buildings should therefore be required to reach very high efficiency standards. However, buildings have very long lifetimes and therefore ‘deep refurbishment’ of existing buildings is also a key energy efficiency technology.

15. In the transport sector, road transport is the dominant energy use. Vehicle efficiency is influenced primarily by materials (weight), aerodynamics and engine efficiency. In light vehicles (cars and vans), there remains substantial potential for improvement in all three in the short to medium term. In the medium to long term, vehicle electrification offers even larger benefits. It is also important to consider the potential for modal switch. Non-powered modes (cycling and walking) and public transport (buses, trains and other mass transit) are intrinsically more efficient than individual light vehicles, and therefore increased use of these options improves system efficiency.

16. In manufacturing industry, the two most widespread technologies are steam boiler systems and electric drive trains. However, there are also multiple specialised industrial processes, for which key technology options need to be addressed at the sub-sector level. Government has made good progress in analysing the options that directly improve efficiency (BEIS, 2015; BEIS, 2017b). Especially in energy intensive processes, existing technology is approaching optimum efficiency for that process. In future, more fundamental changes may be needed, to different processes, different materials and in how those materials are used, reused and recycled.

17. As set out in the preceding paragraphs, much technology for improving efficiency is already available, so the critical issue is its deployment. It has been established for many years that investment in energy efficiency technologies is not always forthcoming, even where it is cost effective (Eyre, 1998; Sorrell, 2004). Subsequent research has identified multiple causes, meaning that a number of different policy interventions are required.

18. In the longer term, more radical efficiency improvements are also needed. This points to the importance of research and development, as well as deployment support, but also to the need to think broadly about technology options across all the systems that lead to energy demand, for example about transport modal switch and materials efficiency (see below).

19. We also need to think about more than just the magnitude of energy demand. Technologies that change the timing of demand or the fuel type are increasingly important. These are addressed in the next sections.

Looking beyond energy efficiency – flexible demand and storage in electricity

20. There is growing interest in the timing of electricity demand. The driver is the increasing share of variable renewable electricity generation. These technologies are the cheapest zero carbon generation technologies, and therefore their share of generation may rise towards 100% as electricity is decarbonised. This puts a premium on flexible demand, i.e. storage and demand side response and poses questions regarding regulatory changes needed to make flexibility happen at scale.

21. Storage in the electricity system has traditionally been limited to a small contribution from pumped hydropower. Recent cost reductions have made lithium ion batteries viable for providing ancillary services. As costs continue

to fall, and flexibility becomes more valuable, it looks likely that batteries will be economic for diurnal storage. There remains a debate about the relative merits of the three broad options for storage location: close to generation, on the grid and close to the point of use. Widespread use of electric vehicles is important in this context – potentially offering value in balancing the grid as well as reducing energy demand.

22. Demand side response can be provided either by shifting the timing of an energy service (e.g. when washing is done) or by storing energy on the customer's side of the meter, normally in the form of heat or cold (e.g. in a hot water tank, building fabric or refrigerator). Both options require customer acceptance; and the former requires more active customer engagement.

23. Both electricity storage and/or demand side response are only likely to happen at scale through some combination of regulation and time-of-use pricing. Regulation might include the requirement for smart technology within end use devices such as heating controls, refrigerators and washing machines. Time of use pricing implies that electricity is measured with greater time granularity than is traditional in homes, i.e. the roll out of smart metering and accompanying changes to the market balancing and settlement arrangements.

Looking beyond energy efficiency – decarbonising fuels

24. There is broad agreement that delivering the goals of the Paris Agreement implies that UK energy use will need to be largely decarbonised by mid-century. The implications for energy supply are well-known, but the implications for energy demand technologies are also huge, as technologies that rely on direct use of fossil fuels will need to be replaced.

25. Electricity has proven to be the easiest energy vector to decarbonise, so electrification of demand is an obvious route to decarbonisation. Many studies project this driver to make electricity the dominant energy vector, both in the UK (CCC, 2008; BEIS, 2017) and internationally (IEA, 2015; IPCC, 2014).

26. However, there are several end uses of energy where electrification is unlikely to be the solution. End uses that appear technically problematic to decarbonise are:
    - Industrial processes that rely of fossil fuels for reasons other than their energy content, for example as a chemical reductant or feedstock.
    - Freight transport, shipping and aviation, where electrification requires problematic levels of battery storage.

27. Electrification of space heating in buildings also raises problems. The scale and seasonality of space heating demand mean that complete electrification would require either very large increases in generation capacity, much of which would be used with very low load factors (Eyre and Baruah, 2015), or the deployment of seasonal storage technologies that are currently prohibitively expensive.

28. In principle, biomass can be used as an alternative to fossil fuels in all these applications. However there are serious concerns about its availability and its

implications for food production and the natural carbon cycle. In the UK, the practical resource is estimated to be only ~10% of current primary energy demand (Slade et al, 2010), so bioenergy seems unlikely to be an important option in the UK.

29. Recent attention has focussed principally on hydrogen as an alternative low carbon vector. The most likely production options are steam reforming of natural gas with CCS (CCC, 2016), and electrolysis of water using low carbon electricity (Philibert, 2017). It is technically possible to convert the gas distribution grid to hydrogen (Sadler et al. 2016). All these upstream technologies need to be developed commercially. There has been less attention to the implications for end use technologies. Often, the assumption seems to be that hydrogen will simply substitute for natural gas in broadly similar end use technologies, such as boilers, engines and industrial furnaces. In our opinion, this is a mistake. There are opportunities to use hydrogen far more efficiently, especially for motive power and low temperature heating, using technologies such as fuel cells and heat pumps. Developing these needs to be a priority.

Wider technical and social change

30. Our analysis is that technological change will be a critical part of the delivery of the Clean Growth Strategy and a decarbonised economy. But technology alone can never be the complete solution, as technologies are developed, installed and used within broader socio-economic systems. Technologies at the point of end-use in particular are dependent on complex supply chains, and have to meet user needs and expectations. Perhaps, most importantly, the total demand for energy is not a fixed number, for which technology has to provide; it is the outcome of complex human processes, which will change significantly over the course of the energy transition.

31. With this perspective, there is a much bigger set of options for delivering the goals of the Clean Growth Strategy than with a narrower focus of the technologies needed to deliver clean energy. These include options that affect how much energy we need, in what form and when. The following paragraphs provide some examples.

32. UK Government industrial energy efficiency roadmaps include on-site material efficiency options, such as casting of metals to ‘near net shape’, but they exclude material efficiency options involving end users, such as wholly new products, the circular economy and sharing economy business models. For example, the road maps pay significant attention to energy efficiency in the oil refining sector, despite the fact that its main outputs, carbon-based transport fuels and plastics, are becoming socially unacceptable. We believe it would be sensible to place more attention on the technologies, social practices, business models and policies that might facilitate the ‘bigger picture’ changes in the materials and products we use.

33. Similarly, Government analyses tend to assume the continuation of existing trends of growth in freight transport, driven by increased consumption and

trade. But these are not inevitable. Transport patterns are driven by social changes. Already passenger and light goods transport have been affected by the commuting and shopping changes arising from the digital economy. Further developments in communications technologies and radical innovations like autonomous vehicles, may have larger effects.

34. In buildings, it is well-established that supply chains for heating and building work are dominated by low-skill, low-innovation businesses, and that this a major constraint of the rate of building performance improvement. However, new technology and new practices from outside the sector may drive change. Big data from smart meters offers the prospect of real time assessment of building performance, and therefore increased supply chain accountability. And modern methods of construction, including off-site manufacturing, offer the hope of reducing the gap between 'as designed' and 'as built' energy performance.

35. Underpinning many of these opportunities and uncertainties is the pervasive role of digitalisation. The immediate, and most obvious effect is the increasing use of electricity to provide data services, in homes, businesses and specialist data centres. This is not trivial, but neither should its importance be exaggerated. It is probably outweighed by the benefits of information technology for improved control of buildings, appliances, vehicles, industrial processes and power systems. More fundamental are the changes in social practices and business models, enabled by a digital society. These can either increase or reduce energy use. Their future impact is therefore uncertain, but not outside the scope of policy to influence.

Conclusions and implications for policy

36. Our assessment of the evidence is that technology at the point of energy use is likely to be critical to delivery of the goals of the Clean Growth Strategy. This requires action across multiple sectors and uses of energy: in buildings, transport and industry. It includes a broad range of options that affect the demand for the services that energy provides. The objectives include improving energy efficiency, increasing the flexibility of electricity use and decarbonising fuels. This is a broad and complex agenda. It points to the need for technological research, development and demonstration, but also for how the mass deployment of these technologies can be encouraged through improving supply chain skills and better energy user engagement.

37. The implications for policy are complex. There is no single 'silver bullet' solution. A policy mix will be required that includes support for innovation, incentives, information and regulation. Ambitious and well-enforced standards for buildings, appliance and vehicles are needed to act as drivers of change.

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