Accelerating energy storage innovation – what is needed and how can it be achieved?

Peter G. Taylor[1,2,3] and Jonathan Radcliffe[4]

[1] Centre for Integrated Energy Research, University of Leeds, UK
[2] Low Carbon Energy Group, School of Chemical and Process Engineering, University of Leeds, UK
[3] Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, UK
[4] Birmingham Centre for Energy Storage, School of Chemical Engineering, University of Birmingham, UK

Abstract

Energy storage could be a key option for providing increased energy system flexibility in the UK and many other countries, but is not yet a mature technology. While the UK has substantially increased the funding for energy storage research, development and demonstration in recent years, the levels are still far below those for many other energy technologies. The rapid deployment of energy storage is also hampered by a regulatory environment that does not sufficiently value the flexibility that storage can provide. In this paper we use three approaches - a review of the innovation literature, an analysis of current innovation support and a set of interviews with stakeholders - to provide some initial guidance to policy-makers and others about how to accelerate energy storage innovation. We conclude that key priorities should include supporting a greater range of storage technologies, a scaling up manufacturing and demonstration activities and taking a whole systems perspective.

1. Introduction

Energy storage is increasing being recognised both in the UK and globally as an important component of a future low-carbon energy system, due to its ability to provide energy system flexibility by helping to balance supply and demand (Taylor *et al*, 2013). The term 'energy storage' encompasses a family of technologies, ranging across orders of magnitude in time and energy scales, covering the storage of electrical and thermal energy (and potentially other vectors, such as hydrogen) by means of a number of different physical processes. The various storage technologies are also at different stages of maturity; with some (such as pumped hydroelectricity and sensible heat storage) having been fully commercial for many years, while others (for example, certain battery chemistries and some materials for latent heat storage) still require fundamental research and development.

In the UK, public investment in energy storage research, development and demonstration has increased substantially in recent years, with the aim of accelerating the commercialisation of a number of different technologies (Winskel *et al*, 2014). However, the ultimate success of energy storage could crucially depend on the timing of its availability, relative to the rapidly rising deployment of variable renewables expected by the early 2020s. If the technologies are not market-ready in the next few years and other barriers to their widespread deployment remain, then traditional means of providing flexible response will be taken-up to help meet the challenges imposed on the system by high penetrations of wind, solar and nuclear, combined with changes to the pattern of energy demand. This could leave no market for disruptive alternatives and so potentially lock-in sub-optimal energy systems making decarbonisation a more costly process.

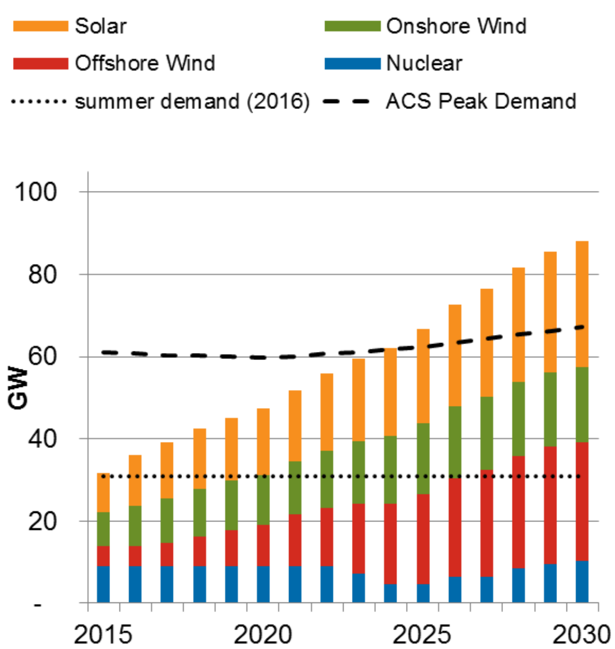
Our paper addresses this innovation challenge by drawing some initial lessons from research that is aiming to provide guidance to policy-makers and funders about the most appropriate way to support commercialisation of different forms of energy storage in the UK. The remainder of the paper is structured as follows. Section 2 briefly describes some of the key challenges facing the UK energy system and the potential role of energy storage in addressing these. Section 3 reviews a selection of the key literature on energy innovation, drawing preliminary conclusions on the implications for energy storage. Section 4 provides an overview of the current energy storage innovation support landscape in the UK. Section 5 presents the results from a set of stakeholder interviews on the role of energy storage and the opportunities and barriers that it faces. Finally, section 6 presents some initial conclusions and identifies areas for further research.

2. Context: The UK's energy system

The UK's energy system will face growing pressures over the next 15 years if decarbonisation targets are to be met. Energy system challenges will be felt on timescales of seconds through to seasons, at national and local levels, and cover electricity, heat and transport sectors (Energy Research Partnership, 2011; Taylor *et al*., 2012).

Considering electricity, National Grid's latest Gone Green scenario (National Grid, 2016) illustrates how 'inflexible' generation capacity, from wind, solar and nuclear, could increase substantially through the 2020s, compared to demand for electricity (Figure 1).

Figure 1 'Inflexible' generation capacity, and electricity demand (in summer daytime: dotted line, in winter Average Cold Spell: dashed line), from National Grid's 'Gone Green' scenario for GB.



In the winter, inflexible capacity (ignoring the contribution from solar, which makes a small contribution in winter) could account for over half of demand by the early 2020s, and almost meet full demand by 2030. The impact of rapid variation in wind generation, up or down, will be significant. In the summer the amount of ‘inflexible’ capacity (consisting solar, wind and nuclear) already stands at over 30GW, approximately that of the summer midday demand when solar generation would peak. Even though generation from solar and wind are unlikely to reach their rated capacity simultaneously, there is clearly a growing likelihood of excess supply at a national level in the 2020s, before taking into account local network constraints.

Electrical and thermal energy storage provides a potential solution to the need for increased flexibility across the energy system. Key analytical work has been undertaken by Imperial College over the last four years that shows the high potential value of energy storage to the energy system under decarbonisation scenarios. A 2012 report for the Carbon Trust (Imperial College, 2012) found system savings from storage of £2bn in 2030, reaching over £10bn per year in 2050. This was reinforced in a 2015 report for the Committee on Climate Change (Imperial College and NERA Economic Consulting, 2015), which also concluded that if regulatory barriers were removed, the savings could reach £7-8 bn per year in 2030.

However, energy storage technologies will need to compete against alternative approaches including demand side response, interconnection and other technologies for providing heat, power and transport services.

3. The innovation studies literature

In this section we introduce some of the key concepts relevant to energy technology innovation and transitions, review some of the most common frameworks used to explore innovation processes and highlight a number of key findings that could be relevant to the study of energy storage innovation. The literature on these topics is very extensive and so what follows can only be a very brief and therefore incomplete overview.

Key concepts in energy technology innovation and transitions

Grubler and Wilson (2014) describe how technologies travel on a journey “*from birth (invention, innovation), to adolescence (growth), maturity (saturation), and ultimate senescence (decline driven by competition from newer and more attractive innovations)*”. The technology innovation and transitions literature seeks, in part, to identify, describe and explain the drivers, mechanisms and contextual factors that lie behind this technology journey and how “directed innovation” might help accelerate the process.

Early models of the innovation process from the mid-20th century largely characterised the journey as a linear process from invention through innovation to widespread diffusion, with the success or otherwise of this process attributed mainly to the characteristics (e.g. cost, performance) of the technology itself. Initially much of the focus was on the role of basic R&D providing “technology push” towards market deployment, but later this was complemented by studies highlighting that “market pull” was often also important.

A further distinction in the early literature was drawn between incremental and radical innovations. While there is no universal definition of either term, they are often distinguished with respect to the degree of new knowledge involved and the scale and significance of the economic and other consequences of the innovation (Bell, 2012). Grubler and Wilson (2014) explain that while Usher (1929) pointed to the significant compounded effects of numerous, small, incremental innovations, Schumpeter (1942) emphasised the importance of radical technologies driven by entrepreneurship and competition. Grubler and Wilson (ibid, p. 6) also highlight that the transformative role that technology can play arises from clustering (combinations of technologies) and spillover effects (applications outside the initial sector/use).

While many of the ideas on innovation introduced during the last century are still seen as relevant, our current understanding of innovation processes has become more complex and nuanced. More recent literature emphasises that the technology journey is unlikely to be linear, with many feedbacks and loops existing between the stages of innovation. Much more attention is also now paid to how non-technology factors can be important in the technology journey – the study of so called systems of innovation – covering aspects such as changes in institutions, markets, policies, regulations, business models and user practices and which are understood to “co-evolve” through mutual interaction and hence impact the overall process of innovation (Foxon, 2011).

These co-evolutionary and feedback processes also help to explain how path dependencies can arise in the trajectories of socio-technological systems if they become mutually reinforcing (Twomey and Idil Gaziulusoy, 2014). The innovative process is thus both a product of – and reinforces - the so-called path dependency (Greenacre, 2012). A further reinforcement mechanism arises from the process of technology learning, which describes improved (technological) knowledge derived from either production and/or user experience. Such increasing returns to adoption mean that the more a technology is adopted, the more likely it is to be further adopted (ibid). A combination of path dependence and increasing returns to adoption tends to favour incumbent technologies against newcomers, leading to lock-in of the existing technological system (Unruh, 2000).

This lock-in is one of the reasons why various authors have highlighted the extended time required for the technology innovation journey from invention through to widespread adoption (Kramer and Haigh, 2009; Wilson, 2014). A recent review by the UK Energy Research Centre found that across 14 different energy technologies, the average time from invention to widespread commercialisation was 39 years (Hanna *et al*., 2015). Furthermore, the shortest average timelines (29 years) were for those innovations that replaced existing products, while innovations aimed at entirely new markets took considerably longer (average of 42 years).

Frameworks for studying energy technology innovation processes

Two distinct strands of innovation research have emerged over the last 20+ years – technology innovation systems (TIS) and the multi-level perspective (MLP) - and the application of these frameworks now dominate much of the research on energy technology innovation and transitions.

The TIS approach usually focuses on a specific technology and “*seeks to understand its success or failure on the basis of the performance of the TIS*” (Twomey and Idil Gaziulusoy, 2014). Early literature focused on identifying the structure of the TIS (Carlsson and Stankiewicz, 1991) and while there is no unique classification, a typical typology is that of Wieczorek and Hekkert (2012) who identify actors, institutions, interactions and infrastructures. Later the framework was enriched by considering the “functions” of the TIS, which can be fulfilled in a number of ways. Again different lists of these functions exist, but a commonly used typology was described by Hekkert *et al*. (2007) consisting of entrepreneurial activities, knowledge development, knowledge exchange, guidance of the search, formation of markets, mobilization of resources, counteracting resistance to change.

The strength of the TIS approach lies in its analytical power, combining both the analysis of structure and function of the innovation system. So for instance, Bergek *et al*. (2008) describe “*a practical scheme of analysis for policy-makers*”, which consists of six steps that an analyst should follow to apply the framework. The TIS also explicitly recognises the role of strategies and agency and so can be used to explore how policies can help direct innovation.

However, the TIS can be considered to be myopic with regards to technology transitions. The success of an innovation is regarded largely as a consequence of the performance of the corresponding innovation system. The wider systems perspective is not explicitly represented, so for example an external institution that hinders the innovation process is treated simply as a “blocking mechanism”, with no consideration of whether this might be as the result of a strategic intervention from an incumbent actor (Markard and Truffer, 2008).

In contrast, the MLP takes this broader transitions perspective, emphasising how innovation occurs within a societal context (Rip and Kemp, 1998). Specifically, it considers the process of technological transition to be an interactive process of change between three different levels:

- Landscape (macro), which describes the overall socio-technical environment
- Regime (meso), which comprise the structures that represent current practices and routines, including the dominant rules and technologies.
- Niche (micro), in which space is created for radical experimentation and radical innovation and from which new technologies can emerge.

Strategic Niche Management (SNM) builds on the MLP approach, taking a technology centred approach to examine which processes determine successful niche development of a particular technology or technology system. It therefore has a more normative and governance oriented focus than the original MLP (Schot and Geels 2008).

The strengths of the MLP are that it explicitly recognises the systemic nature of innovation processes representing the interplay between the stabilising mechanisms at the regime level, combined with the emergence of radical innovations at the niche level and the role of landscape pressures However, it is weaker when it comes to the roles and strategies that different actors play in such processes and their degree of agency (Markard and Truffer, 2008).

Key findings relevant to storage

Our initial review reveals that there is a rich literature on technology innovation and transitions that can be used to help inform the study of innovation processes for energy storage. The different perspectives reveal the complexity of the environment in which innovation occurs and the numerous factors that can influence its pace and direction and so go beyond the neo-classical economic perspective that sees the support for innovation as merely addressing “market failures”.

Some important lessons from this literature include:

- Any analysis of storage innovation needs to go beyond a narrow consideration of "improving" the characteristics of the technologies expressed in terms of cost and performance. The (rate of) adoption of energy storage could significantly depend on issues such as the regulatory and policy environment, the development of appropriate business models and the levels of public acceptance.
- There is a significant danger that the socially desirable level of energy storage deployment may not be achieved in the market as a result of path dependency and "lock-in" of the existing technological regime.
- Government should pay attention to all aspects of the technology innovation system for storage to make sure that it is functioning effectively. Areas that might benefit from strengthening include knowledge exchange, formation of markets and counteracting resistance to change.
- It takes time for innovation systems to form and mature, especially in the case of more radical disruptive technologies. This makes an effective innovation system for storage an urgent priority.

4. Support for energy storage innovation in the UK

Since at least 2000, the potential benefits of energy storage in a system with high penetration of variable renewable generation from wind have been recognised. The Royal Commission on Environmental Pollution stated "*Government must stimulate research into solving the problems that large-scale intermittency and embedded generation would pose to the electricity supply system as a matter of urgency*", recommending that "*the Government promote research and development into new technologies for large-scale energy storage, possibly on a collaborative basis in Europe*." (RCEP, 2000)

This section reviews the measures that have been taken to drive innovation in energy storage in the UK, considering support for technology development and the policy/regulatory framework.

Innovation funding and mechanisms

We have analysed the following records of public sector funded projects for energy storage in the UK:

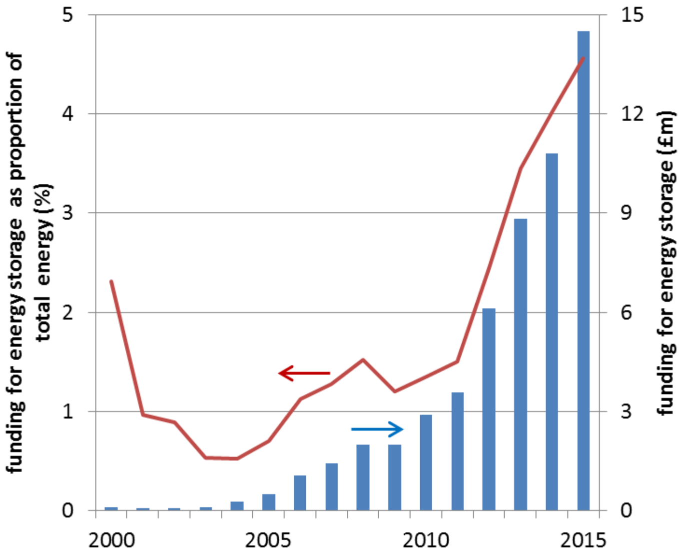
1. For the Engineering and Physical Sciences Research Council (EPSRC) funding was tracked from 2006 to 2015. The EPSRC 'Gateway to Research' was searched for projects with "energy storage" in the title or abstract and records were checked to be relevant to the energy system, and marked according to the application and technology area. Separately, the cost of the capital facilities funded by the 'Eight Great Technologies' call was quantified from the EPSRC 'Grants on the Web'.
2. For Innovate-UK (previously called the Technology Strategy Board), we searched the database (HM Government, 2016) for projects with "energy storage" in the title or description between 2004 and 2015. No further filtering was undertaken.
3. For Department of Energy and Climate Change (DECC) funded activities, news releases have given levels of funding for each demonstration project, and overall level of funding for other specific calls (HM Government, 2014).

4. For funding from the energy market regulator, Ofgem, we have energy storage considered projects supported under Tier 1 and Tier 2 of the Low Carbon Network Fund (LCNF) (Electricity Networks Association, 2016).
5. The UKERC Research Register database holds pre-2006 data on energy R&D funding from across the UK public sector, though not covering items 3 or 4 above, with projects independently classified according to IEA energy category (UKERC, 2016).

Funding from data sources 1 – 4 above is given when the project is awarded; for source 5, expenditure is divided across the life of the project.

Figure 2 is based on UKERC data and shows that there has been a rapid increase in support for energy storage technologies since 2005, though from an almost insignificant base. However, this funding was far below that for variable renewable technologies in the first decade of the century (
Table 1).

Figure 2 UK public sector funding for energy storage technologies



Source: UKERC Research Register

Table 1 Cumulative UK public sector funding for selected renewable energy technologies 2000 – 2009. ()

IEA energy category	Funding 2000 – 2009 (£k)
Energy storage	7,551
Wind energy	25,816
Solar energy	37,721
Ocean energy	39,511

Source: UKERC Research Register

As different agencies support funding at different stages of innovation, we can see in Figure 3 how support for early stage research (funded by EPSRC) preceded a spike in later-stage innovation funding between 2011 and 2013, from Ofgem, the Energy Technologies Institute (ETI) and Government. In 2012, George Osborne as Chancellor gave a speech at the Royal Society which made energy storage one of the Government’s ‘Eight Great Technologies’, backed-up by then Science Minister, David Willetts, in 2013 (Willetts, 2013). This led to a continued increase in research funding, but late-stage support has since diminished.

Figure 3 Public sector funding for energy storage in the UK.

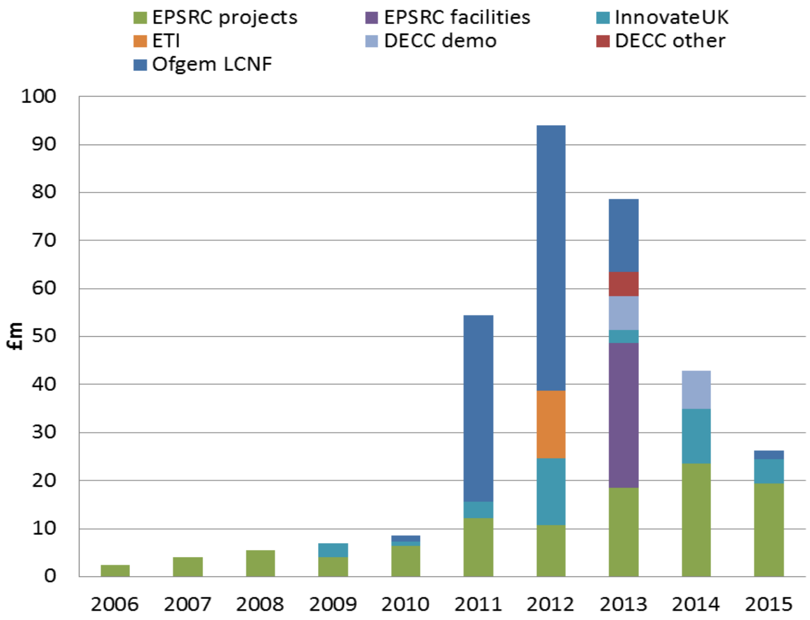
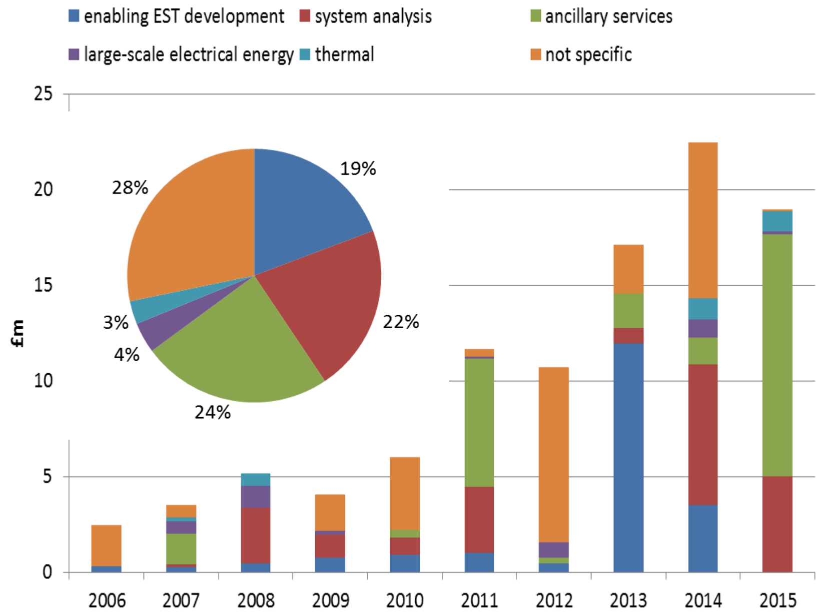


Figure 4 EPSRC funding for energy storage by main technology service. Inset: proportions of total funding 2006 – 2015.



Looking more closely at the support from the EPSRC, Figure 4 gives the funding according to a number of different categories: by technology, by the main service provided[1], and also that provided for analysis of how energy storage could be integrated into energy systems. We find that over 60% has been for projects that are not focusing on a specific storage technology, and when projects have been funded for a particular technology, the predominant area has been electrochemical cell (rather than flow) batteries. Relatively small amounts of funding have been for large scale electrical or thermal energy storage.

Coordination

It is notable that public sector funding for technology innovation has come from several separate organisations, with different missions: high quality research to advance knowledge and technology (EPSRC), growing the UK economy (Innovate-UK), accelerating the development of low carbon technologies an economies (ETI and Carbon Trust), and protecting the interests of existing and future electricity and gas consumers (Ofgem).

The Low Carbon Innovation Coordination Group (LCICG) was established to "seek to coordinate public sector support, improve communication and build a shared evidence base within low carbon innovation". However, a key funder of energy storage demonstration activities, Ofgem, has not been a core member. Though LCICG's specific coordination activity on storage has not been publically documented, it has published Technology Innovation Needs Assessments (TINAs) on Electricity Networks and Storage (2012, with an update expected), and separately on Heat (updated in 2016) which includes thermal storage technologies.

Deployment support

Storage has only been built at any scale under a nationalised industry in the UK and, since market liberalisation, there has been a lack of specific 'market pull' mechanisms to drive innovation and investment in such new technologies. Policy and regulatory barriers to the deployment of energy storage technologies have been recognised for some time (Energy Research Partnership, 2011 and Castagneto Gissy *et al*, 2016), but policy makers have taken an active interest in energy storage only recently.

In the 2007 Energy White Paper 'Meeting the Energy Challenge' (DTI, 2007), there is brief reference to the possibility of electricity storage being economically viable sometime in the future. Only following the 2008 Climate Change Act 2008, and 2009 EU Renewable Energy Directive when the Low Carbon Transition Plan (DECC, 2009) is published in 2009 is the balancing potential of energy storage described. The joint Government-Regulator Smart Grid Forum was then formed in 2011 and in August 2012 it recommended further analysis in areas of regulation and ownership models for energy storage (Smart Grid Forum, 2012). The final report of the relevant Work Stream 6, in 2015, made a series of actions and recommendations for changes to regulation.

[1] 'Ancillary services' includes electrochemical batteries, supercapacitors and flywheels; 'large scale energy storage' includes flow batteries and thermo-mechanical; 'enabling EST development' includes projects which are not developing storage technologies themselves, but will enable their development, such as on materials.

The first serious work by Government to address the energy policy challenges was signalled with the announcement of a ‘Call for Evidence’ on energy storage (Hansard, 2016), though this has since been delayed and broadened to cover a ‘smart system routemap’.

Recently, some market instruments have been introduced that provide opportunities for energy storage in the UK. Early policy documents for the Government’s Electricity Market Reform package noted the advantages of storage and its contribution “to a better functioning market”, with plans to allow its participation in transitional arrangement for the Capacity Mechanism (DECC, 2012). However, final proposals focused on Demand Side Response to reduce demand at times of system stress. Smaller-scale storage could play a role ‘behind the meter’ in this context, alongside embedded generation, but the limited contract length offered works against investment in new technology.

In August 2016, National Grid as the System Operator tendered for 200MW of ‘enhanced frequency response’ services. This targeted battery energy storage that would be able to provide sub-second response, which could then reduce the procurement of existing frequency response services.

In the meantime, policy makers and regulators in other markets have introduced deployment support mechanisms, including financial incentives for domestic energy storage (in Germany) and mandated storage capacity (in California) (Castagneto Gissy *et al*, 2016).

5. Stakeholder interviews

In addition to the analysis of UK innovation support, we undertook structured interviews with 12 stakeholders in the UK to get their perspectives on the potential role of energy storage in a future low-carbon energy system and the opportunities and barriers to deploying storage technologies.[2] The stakeholders comprised representatives of the following types of organisations (numbers of interviewees in brackets): government and regulators (2), technology developers (3), consulting engineers (1), electricity distribution and transmission companies (3), electricity generation companies (2) and RD&D funders (1).

The interviews were preceded by a brief explanation of the purpose of the overall project and the definition of energy system flexibility, which was described as its ability to cope with events that may cause imbalance between supply and demand while maintaining system reliability in a cost- effective manner.

The need and timing for flexibility

All 12 stakeholders believed that the need for system flexibility would increase substantially over the period to 2030 if current energy policy goals were maintained. They highlighted a range of supply and demand-side developments that would lead to this need for additional system flexibility (Figure 5). There was unanimous agreement that the expected increase in variable renewable generation would be a very important driver for increased system flexibility. The vast majority of interviewees also thought electric vehicles would be either a

[2] The stakeholder interviews were undertaken as part of a project by the authors that was funded by the UK Foreign and Commonwealth Office and examined energy storage innovation in the United Kingdom and Korea. Further details are available at http://www.lowcarbonfutures.org/energy-storage/korea.

very important or important driver, although some noted that electric vehicles could also be a source of flexibility and others doubted whether there would be sufficient deployment by 2030 to require greater system flexibility. Many stakeholders thought electric heating to be an important driver, although others either doubted that the deployment by 2030 would be sufficient for it to be important or alternatively believed that the load would be sufficiently predictable not to require increased system flexibility. The majority of stakeholders considered that combined heat and power and district heating would play only a minor role in driving the need for flexibility. Most stakeholders viewed space cooling as being of minor importance or not relevant, often citing an expectation of limited deployment in the future. Other factors that were highlighted as important or very important drivers for increased system flexibility were a new nuclear or carbon capture and storage plant running on baseload.

Figure 5: Drivers for increased energy system flexibility over the period to 2030

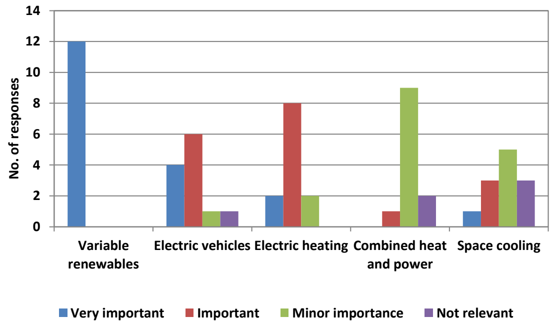


Figure 6: Role of options in providing flexibility to the energy system over the period to 2030

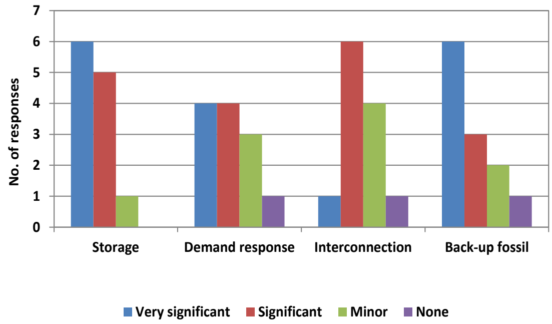


Figure 7: Durations over which energy storage is the best-placed option to provide flexibility to the energy system

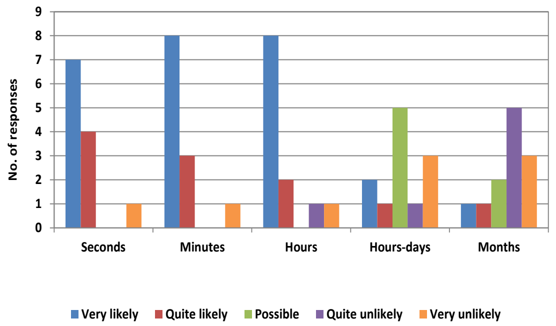


Figure 8: Likelihood of additional energy storage being located on different parts of the system

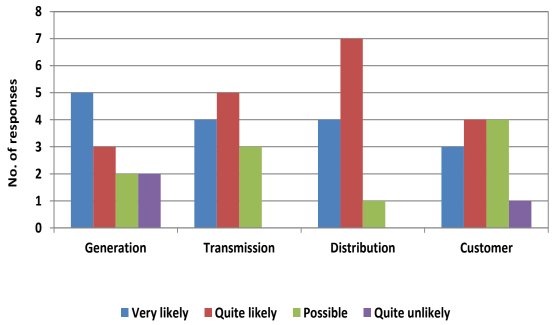


Figure 9: Importance of barriers to the deployment of energy storage over the next 5-10 years

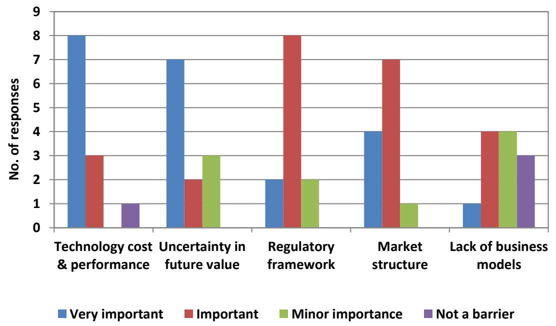
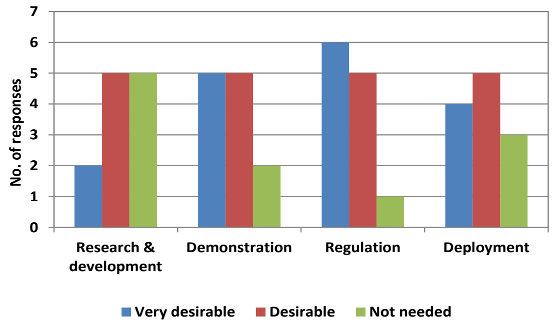


Figure 10: Desirability of different forms of government support for energy storage



There was much less agreement about when the current energy system would prove to be insufficiently flexible to cope with expected developments. However, the majority of stakeholders felt that this would be most likely in the period 2020 – 2025. Many emphasised again that developments on the supply-side would be the dominant cause, with some noting that the pace of supply-side change would require increased flexibility in the system before it could be provided by the demand-side.

Role of different options in providing system flexibility

Most stakeholders anticipated that a range of options would be needed to provide system flexibility over the period to 2030 (Figure 6). The vast majority of stakeholders expected storage to play a very important or important role in this timeframe (e.g. additional capacity in the range 5 – 15 GW), with a majority also expecting back-up fossil capacity also to be very important or important (e.g. > 10 GW). Views on the roles of demand-side response and interconnection were more mixed, but none the less more than two-thirds of stakeholders though demand-response would be very important or important (e.g. 2 – 10 GW), while more than half of stakeholders believed the same about interconnection (e.g. doubling of current capacity). Respondents highlighted the scalability of storage and its ability to provide multiple services as reasons why they believed it would be play a significant role.

Storage was considered best-placed to provide flexibility to the energy system over periods of between seconds and hours, with the vast majority of stakeholders rating these durations as very likely or quite likely (Figure 7). Durations of hours – days were thought at least possible by just over half of respondents. Most respondents seemed to have battery technologies in mind when giving these replies. Those stakeholders who believed that longer durations would be possible sometimes mentioned that it was heat storage that would fulfil these longer timeframes. A few stakeholders mentioned that hydrogen could also provide longer storage durations in the future.

When thinking about where on the system storage technologies were most likely to be located, then distribution level storage was the most popular choice - seen as very or quite likely by virtually all stakeholders (Figure 8). A number of reasons were given for this including that the small capacity size of some storage technologies were better suited to distribution rather than transmission, that the targets for distribution network operators could be easily realigned to drive storage uptake, that it could address grid constraints and that it was easier to have storage downstream in the value chain. Two-thirds or more also saw generation and transmission as likely or very likely locations for storage. In the case of generation the main role was seen as enabling the integration of variable renewables, such as wind farms. At the transmission level, the reasons given included economies of scale, the value of storage for fast response and dealing with volatility and the market to provide National Grid with system services. Customer-level storage was seen less favourably, but this option was still rated very or quite likely by more than half of respondents. Those in favour often highlighted the role of storage alongside PV systems.

The energy storage innovation system and the role of Government

Technology cost and performance was seen as a very important or important barrier to widespread deployment of energy storage by all but one of the stakeholders, with uncertainty of future value also being highlighted as very important by more than half of respondents (Figure 9). The regulatory and market framework in the UK was also seen to be an important barrier. A number of respondents highlighted in particular uncertainty in the market and regulatory structure as a problem, rather than necessarily any need for further reform. The lack of business models was considered to be less of a barrier, with a number of respondents believing that business models would emerge if the commercial case was strong.

When asked about their priorities for innovation stakeholders highlighted cost reduction (including O&M costs), improvements in performance (including increased lifetime, higher energy density, increased cycling) and new business models (somewhat contradicting the earlier assertion from some stakeholders that these would emerge naturally).

When asked whether the government should provide further support for the development / deployment of energy storage, three quarters of the respondents felt that they should, with the remainder being equally split between views that were neutral, slight disagree and strongly disagree. Those that supported agreement often expressed the view that government supported a range of other energy technologies in different ways, but so far has done relatively little for storage. Those that were neutral or disagreed either felt that government was doing enough already to support storage or that further work was needed to determine what kind of government support would be most appropriate.

In terms of what support was most needed, all but one stakeholder felt that regulatory reforms to remove barriers and create a more level playing field were either very desirable or desirable (Figure 10). There were also strong views in favour of additional support for demonstration, with a large majority believing this to be very desirable or desirable. Views on support for deployment were more mixed, although three-quarters of stakeholders thought that some form of deployment support was either very desirable of desirable. There was least support for further investment in R&D with nearly half of respondents believing this to be not needed.

6. Conclusions

The UK energy system will need to become more flexible in the 2020s and beyond to cope with potential imbalances between supply and demand. Energy storage is a service which can contribute towards this improved flexibility, and a number of technologies are being developed which can operate across a wide range of storage time-scales. Accelerating technological innovation could drive down costs and improve performance, bringing energy system benefits and business opportunities in the UK. This will also need to be coupled with energy policy and market frameworks which value flexibility and business models that can extract the “stacked benefits” which storage provides.

Energy storage provides a case study for technology innovation with interesting characteristics: its future market value will largely depend on the extent and nature of changes in the composition of both supply and demand technologies (so, in the language of MLP, future changes in the ‘regime’ will be important); its value cannot be fully monetised in current market conditions – so there could be the case for the creation of protective “niches”; and, though it is often considered as a single technology, there are a large number of very different approaches to storing energy according to the application (with the potential for spill-over effects).

Whilst storage services over timescales of seconds – minutes will be more highly valued in the near-term for the UK's energy system, the prospect of > 50% energy being delivered by variable renewables and inflexible nuclear in the mid-2020s indicates that large quantities of energy store over hours – days will become increasingly important to ensure secure supplies. However, at the moment most stakeholders do not see energy storage as the best-placed option to provide flexibility over these timescales.

While this need has been recognised for many years, and not just in the UK, there has been a lag in support, and lack of vision across the innovation landscape, which would enable the appropriate technologies to be developed to meet the needs:

- Early stage R&D has focused on electrochemistry technologies, which are most suited to electricity storage from minutes to hours;
- Technology demonstrators funded by DECC have covered a relatively small number of technologies, with the danger of locking out potential alternatives.
- The regulator has funded demonstration of learning from the operation of energy storage at the distribution level, with a focus on network support.

The overall level of funding for energy storage technology innovation, while increasing, has been low in comparison to other technologies, such as renewables, and not sufficiently joined-up. Further, it has not been sufficiently supported by policy to provide confidence to private sector investors. This would indicate the need to strengthen some of the functions of the storage innovation system, such as resource mobilisation, knowledge exchange and guidance of the search.

The automotive industry has benefited from clear policy signals to decarbonise transport in a sector where consumer choice drives competition. Hence we see large scale investment in battery technologies for electric vehicles that are rapidly reducing costs in a particular energy storage market segment and also having spillover impacts into other markets, such as smaller-scale stationary applications.

If the UK is to really embrace the potential offered by energy storage, all parts of the innovation system need to be addressed so that it functions as a whole. We will be undertaking further research to explore in more depth some conclusions that we draw from our initial analysis:

- In R&D, excellent science, where there is internationally renowned research, should continue to be supported; but capability needs to be grown in new areas to develop new materials and processes for technologies which could have a significant energy system impact.
- Scaling-up to support manufacturing and demonstration activities (as has been done in the auto sector) will be crucial.
- Policy and regulation needs to look ahead to the requirements of the energy system in the 2020s, while industry will need to consider new business models for maximising the value of energy storage.
- Innovation support must consider how the different parts of the 'whole energy system' will co-evolve, including heat and transport, and across temporal and spatial scales.

Our findings are intended to provide guidance to policy-makers and industry and to support existing efforts such as the National Roadmap for Energy Storage that is being developed by the EPSRC funded Energy SUPERSTORE Hub.

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