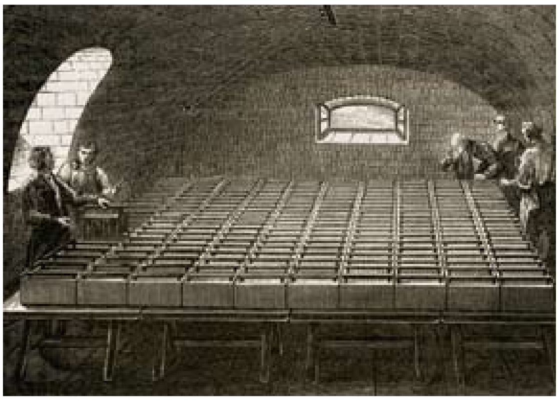
June 2011 Energy Research Partnership Technology Report

# The future role for energy storage in the UK
# Executive Summary and Conclusions



Energy Research Partnership

# The Energy Research Partnership

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.

The Partnership has been designed to give strategic direction to UK energy innovation, seeking to influence the development of new technologies and enabling timely, focussed investments to be made. It does this by (i) influencing members in their respective individual roles and capacities and (ii) communicating views more widely to other stakeholders and decision makers as appropriate. ERP's remit covers the whole energy system, including supply (nuclear, fossil fuels, renewables), infrastructure, and the demand side (built environment, energy efficiency, transport).

ERP is co-chaired by Professor David Mackay, Chief Scientific Advisor at the Department of Energy and Climate Change and Nick Winser, Executive Director at National Grid. A small in-house team provides independent and rigorous analysis to underpin ERP's work.

ERP is supported through members' contributions.

## ERP MEMBERSHIP

**Co-Chairs**

| | | |
|---|---|---|
| Prof David MacKay FRS | Chief Scientific Advisor | DECC |
| Nick Winser FREng | Executive Director, Transmission | National Grid |

**Members**

| | | |
|---|---|---|
| Professor Julian Allwood | Senior Lecturer | University of Cambridge |
| Dr Peter Bance | Chief Executive Officer | Ceres Power |
| Dr David Clarke | Chief Executive | Energy Technologies Institute |
| Tom Delay | Chief Executive | Carbon Trust |
| Peter Emery | Production Director | Drax Power |
| David Eyton | Group Vice President for Research & Technology | BP |
| Dr Mike Farley | Director of Technology Policy Liaison | Doosan Power Systems |
| Martin Grant | Managing Director Energy | Atkins |
| Gordon Innes | Director, Low Carbon Business | BIS |
| Dame Sue Ion FREng | | Royal Academy of Engineering |
| Neville Jackson | Chief Technology and Innovation Officer | Ricardo UK |
| Allan Jones | Director | E.ON UK |
| Paul Lewis | Managing Director, Industries & Policy | Scottish Enterprise |
| Prof John Loughhead FREng | Executive Director | UK Energy Research Centre |
| Dr Ron Loveland | Head of Sustainable Energy & Industry | Welsh Assembly Government |
| Ian Marchant | Chief Executive | Scottish and Southern Energy |
| Duncan McLaren | | Friends of the Earth |
| Dr John Miles | Director | Arup |
| Neil Morgan | Head of Energy | Technology Strategy Board |
| Graham Pendlebury | Director Environment and International | DfT |
| Dr Graeme Sweeney | Executive Vice President, $CO_2$ | Shell International |
| Stephen Trotter | Managing Director, Power Systems | ABB |
| Alison Wall | Programme Manager, Energy & Climate Change | EPSRC |
| Prof Jeremy Watson FREng | Chief Scientific Advisor | CLG |

**Cover images:**
**Llyn Stwlan reservoir, UK, aerial image.** Llyn Stwlan, near Ffestiniog in North Wales, the upper reservoir of the UK's first major pumped storage power facility with output of 360MW.
**Royal Institution Battery 1807.** 1807 engraving showing the most powerful electrIc battery of the time at the Royal Insitution, London. This was constructed by William Wollaston for Humphry Davy.
**Hot Water Storage Tank.** A 1500 litre hot water storage tank in the basement of a 'smart house'.

## Contents



## The Energy Research Partnership Technology Reports

ERP Technology Reports provide insights into the development of key low-carbon technologies. Using the expertise of the ERP membership and from wider stakeholder engagement, each report identifies the innovation challenges that face a particular technology, the state-of-the-art in addressing these challenges and the current activity in the area. The work identifies critical gaps that will prevent key low-carbon technologies from reaching their full potential and makes recommendations to address these gaps.

This report has been prepared by the ERP Analysis Team, led by Jonathan Radcliffe, with input from ERP members and their organisations. The Steering Group was chaired by John Miles (Arup), with Ron Loveland (Welsh Assembly Government), Alex Hart (Ceres Power), Charles Carey (SSE), David Anelli (E.ON), Garry Staunton (Carbon Trust), Gert Jan Kramer (Shell), John Loughhead (UKERC), Richard Ploszek (RAEng), Bob Sorrell (BP), Steven Stocks (Scottish Enterprise), and Tim Bradley (National Grid). The views are not the official point of view of any of these organisations or individuals and do not constitute government policy.

Any queries please contact Jonathan Radcliffe in the ERP Analysis Team (jonathan.radcliffe@energyresearchpartnership.org.uk)

# Executive Summary

Pathways for the UK's energy system to 2050 favour the use of decarbonised electricity to meet many of the energy demands currently served by fossil fuels. This would lead to dramatic changes in the patterns of supply and demand, combining the variability of renewable generation with a strong seasonal profile of electricity demand for heat. Ensuring security of energy supply at timescales of seconds to years will be critical.

The challenges to the energy system will be unprecedented, though manageable if prepared for. Energy storage is in a strong position to be part of the response to these challenges – as outlined in Figure ES1 – with other options being flexible electricity generation, demand side response, and interconnection. However, the implications of achieving emissions goals, beyond simple deployment targets, need to be fully understood so that the transition to low carbon is as efficient as possible.

This report presents a strategic view of the opportunities for electrical and thermal storage to provide a reliable energy supply, setting-out the nature and scale of the challenges that will be faced. We describe how energy storage could go to meeting those challenges and the innovation landscape for further technology development in the UK.

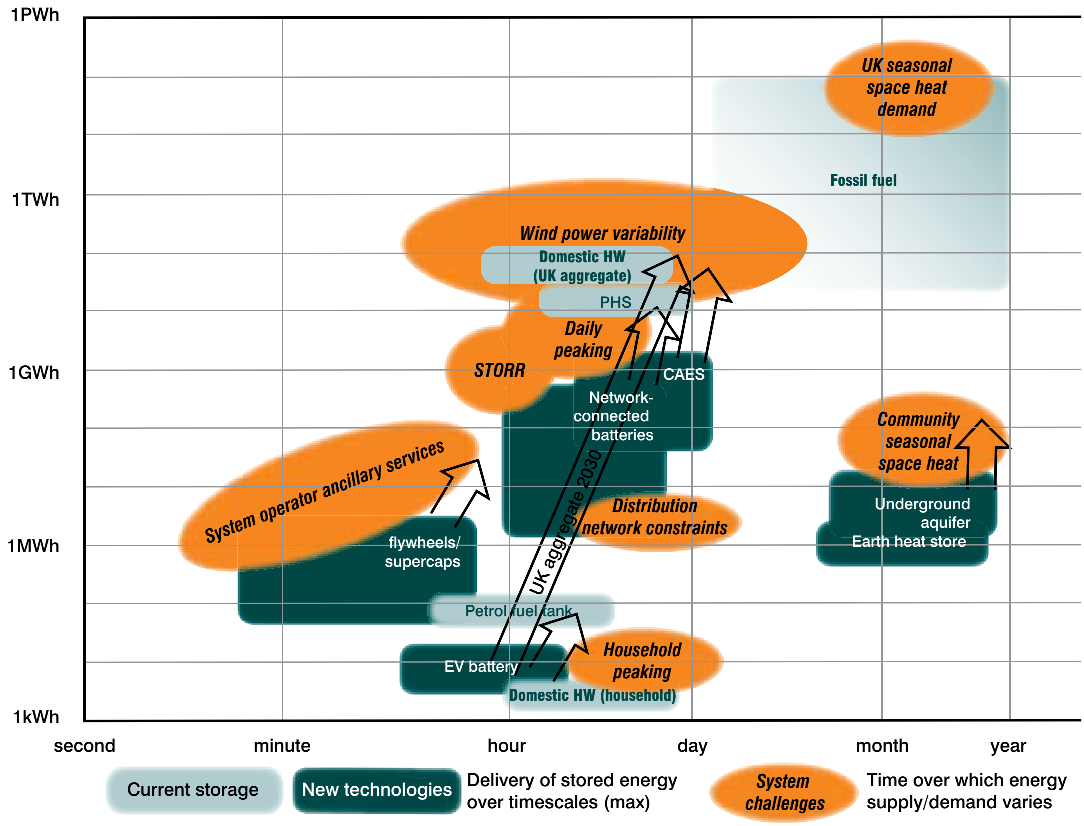



*Figure ES1: Challenges to the UK energy system posed by increased wind and electrified space heating and how they can be met by energy storage technologies, with indicative time and energy scales. Blue boxes show widely deployed technologies. Green boxes show current limits of new technologies, with arrows illustrating their potential application with further development.*

## Our key conclusions are:

Energy storage can help manage the large-scale deployment of intermittent generation and the electrification of space heating. Storage technologies have the potential to substitute for new peaking generation plant and allow the electricity network to handle increasing power flows.

The role for energy storage is poorly described in many pathways to a low-carbon economy. It is a complex technology covering timescales from seconds to months, which needs detailed analysis of systems and sub-systems to identify the economic and environmental benefits it may bring.

New energy storage technologies are unlikely to be deployed on a large scale under current market and regulatory conditions. Both technology cost reductions, and a market framework which recognises the benefits of energy storage, are required to ensure that opportunities to reduce system-level costs in the transition to a low-carbon economy are not missed.

Demonstration of energy storage technologies needs to be scaled-up to show the impact they can have and to guide further underpinning R&D to reduce costs and improve performance. Large-scale trials (in conjunction with demonstration of other network technologies) would help establish the UK as a centre for technology development in a field that is projected to be worth $10s – 100s bn over the next two decades. In general, public sector support for innovation in these technologies should be better coordinated.

Energy storage is an enabling technology; its potential role will be defined by developments across the energy system. Given the pace of change to be experienced over the next decade, a better understanding of both the energy system and policy direction is required urgently to inform investment decisions.

# Recommendations

I. Government should set out its long-term policy direction for energy in the UK to help define the potential role for storage, and the innovation required to meet that role.

II. Funders of energy innovation must set out a strategy for the analysis and innovation of energy storage technologies, coordinating their support and integrating the analysis of potential benefits with technology innovation. It would be in the interests of Government, the regulator and industry to ensure an efficient transition to low carbon which energy storage could enable. These stakeholders should come together with the Research Councils, Technology Strategy Board, Energy Technologies Institute and Carbon Trust, to formulate such a strategy.

III. Further analysis of the potential role of storage in the UK's energy system should be funded. Whole system and subsystem modelling, incorporating the full range of energy storage options across time and energy scales, is needed.

IV. The Technology Strategy Board should consider bringing forward a programme for energy storage technologies, where there is an opportunity for UK businesses and a potential market need. Other bodies which can support large scale demonstration activities, such as Ofgem and DECC, should target energy storage as a priority.

V. Electricity Market Reform and regulatory approaches must recognise the potential benefits of increased energy storage explicitly. Though the underpinning analysis to define its potential role is not fully developed, this should not be a reason to place barriers in the way of its future deployment, even if they are unintended consequences of other policies. There may even be environmental and economic cases for incentivising deployment of such technologies.

VI. The energy storage stakeholder community, covering all elements of research, development, demonstration and deployment, should establish a Strategic Roadmap for Energy Storage in the UK to introduce a coherent approach across the sector.

To replace the functionality of fossil fuels in providing seasonal space heating would be one of the most significant challenges in the transition to a low carbon economy. Coal, gas and oil have high energy densities and are easy to store and transport in the infrastructure that has built up over decades and centuries. Natural gas serves 100s TWh of heat demand, concentrated in the winter months (Figure ES2). Scenarios described by the Committee on Climate Change and DECC's Pathway Alpha include deployment of heat pumps in around a quarter of UK homes by 2030. This could require a 10GW electricity generation capacity operating at relatively low load factors.

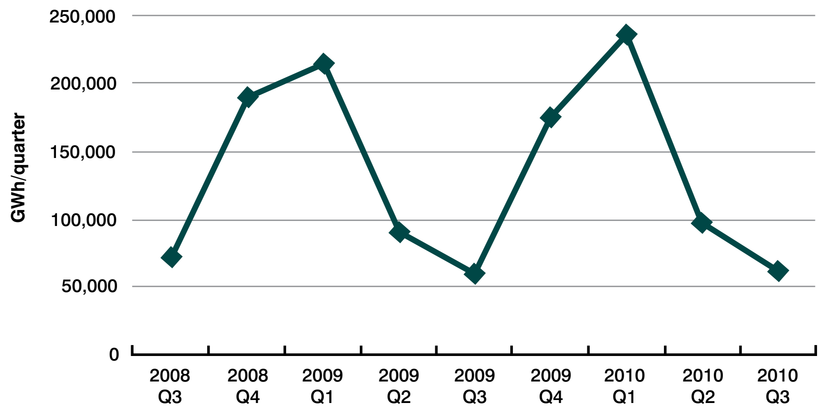



*Figure ES2: Seasonal variation of UK natural gas consumption (DECC Energy Trends 2010).*

On the supply side, 10s GW of on- and off-shore wind is expected to be built over the next two decades, introducing significant generation variability. Lulls in the wind over several days could lead to reduced generation of order TWh (Figure ES3); shorter term fluctuations will challenge system balancing; and high wind generation in periods of low demand could lead to more flexible unabated thermal generation displacing CCS plant.

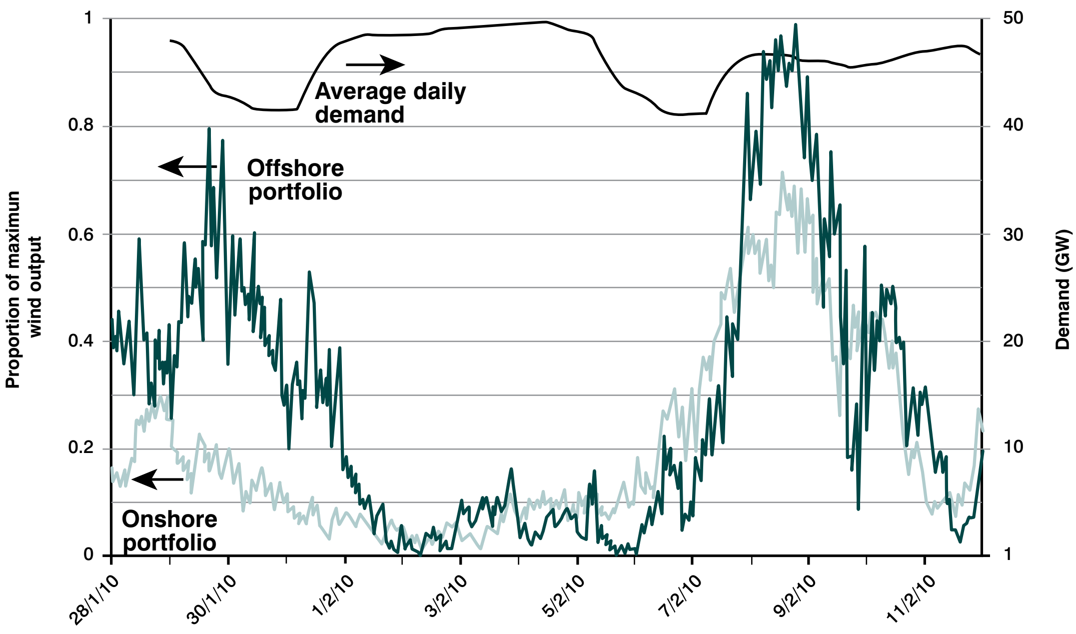



*Figure ES3: Variability in generation from wind at peak demand showing wind generation as a proportion of total capacity (left hand scale) and average demand (right hand scale, drops in demand are weekends). With an installed capacity of 30GW and an expected 35% load factor, this would leave a 1TWh gap (or average 9GW), in a period when the total demand was 5.7TWh. (Data from E.ON.)*

## Options from energy storage

Using electrical and thermal energy storage could avoid some of the need for new plant, and hence the associated costs. Storage could also make most efficient use of the existing and new infrastructure. However, no new grid-scale electrical storage has been commissioned for over thirty years, and the amount of thermal storage in households (as hot water cylinders) is declining.

Installation of electrical storage capability, in locations from the power plant to near end-use, has the potential to provide real economic and environmental benefit to the energy system. There is limited space to expand pumped hydro storage in the UK, so other options for storage need to be explored. Though most focus has been on developing electricity storage, and decarbonised electricity would be the vector for providing the heat service from heat pumps, this may not necessarily be the most effective or practical option. Meeting heat demand from thermal storage must be considered as a alternative. Seasonal 'rechargeable' energy storage as heat may be viable to a limited extent, but is not a solution for large-scale deployment. However, some form of distributed thermal storage could limit the generation capacity required to meet shorter time-scale peaks.

Many new storage technologies are too expensive to move beyond the demonstration phase. But the move to electric vehicles is providing a user-pull that drives R&D in battery technology - reducing costs, improving performance and providing a widespread storage utility that could go beyond the car. In some markets and in some niches, storage technologies are already being deployed commercially.

Energy storage, though, is not the only option to meet the challenges of more variable supply and peaky demand. Greater levels of interconnection, demand side response, as well as flexible thermal generation, could help ease the situation. Hydrogen, as an energy vector and storage medium, may also be an option, though this is also in need of further analysis.

## Preparing for the challenges

The major deficit in the UK is a clear understanding of the role that energy storage and other flexibility options could play in the future energy system. Whole system scenario modelling, which is so influential in determining the direction of energy policy and RDD&D, does not adequately capture thermal and electrical energy storage. This is partly due to the short timescales over which the storage operates, the distributed nature of some forms of storage and the cost/performance uncertainties of technologies. In any case, complexity is added as the system is not in a static equilibrium – the low-carbon transition is expected to see new build generation which could either displace the need for storage (if it is in advance of demand), or require it (if it lags demand).

Detailed analysis of the role of energy storage is needed to guide decisions on:

- Where energy storage devices should be placed in the system
- The characteristics of energy storage which are required at different locations
- The optimal mix of energy storage, generation and demand side technologies
- Where infrastructure strengthening need urgent attention or can be deferred

Indeed, improved understanding using insights gained from models, may show that other potential pathways are feasible options and provide cost-effective alternatives. For example, district heating could be more attractive with large-scale thermal storage. And electrical storage in the home could mitigate against low deployment of EVs which may otherwise provide greater system flexibility. On the other hand, it may be concluded that limited utilisation of thermal plant for balancing and back-up generation will provide the optimal solution for the energy system.

There is a case for scaling-up the demonstration of some innovative electrical storage technologies being developed in the UK to test their operation in the domestic energy system, and to prove their technical capabilities for export opportunities. At a practical level, heat pumps should be tested with adjoining thermal storage to assess performance of the technology, and feasibility of including such storage, especially in the home.

The UK has pockets of expertise in developing some storage technologies in universities and companies, but these are largely uncoordinated, lacking a clear vision of how they could be part of a future energy system.

The role for storage is beginning to be acknowledged in the UK, as the impact of low carbon pathways on the energy system is better understood. Some recent reports are making important contributions to the level of thinking in the field, but there is an urgent need for a strategic and coordinated approach to energy storage in the UK. The Energy Research Partnership will follow-up this high-level report with an assessment of how specific energy storage technologies could meet the energy system challenges. We will work with stakeholders to set out a roadmap for their further development and deployment.

# Conclusions

1. Energy storage has the potential to contribute to meeting the challenges of a low carbon energy system, but has tended to be overlooked in favour of generation technologies. Electrification of heat especially, and substantial deployment of intermittent generation, will make it harder for supply to follow demand. A combination of electrical and thermal storage could mitigate against undue additional investment in conventional generation to meet increasingly peaky demand or low generation from wind.

2. However, energy storage is not a panacea: there are other potential solutions, and system costs are likely to be the overriding factor in determining the chosen technology, which will be strongly system dependent.

3. A rigorous assessment of the role of energy storage against other options in the future energy pathways is not available. Energy system and network models should be developed to include energy storage more effectively and show if it has cost and carbon saving potential.

4. Long-term policy direction for the UK's energy system is also needed to define the potential role for storage.

5. The seasonal profile of heat demand will translate to electricity demand if the UK moves to a scenario where heat pumps provide space heating in place of gas boilers. The role for rechargeable energy storage to cover the scale of this demand appears limited, though there is scope for community or building level thermal storage to have an impact.

6. As wind deployment rises much above 30GW to meet UK demand, the ability to cope with a 5-day lull will rest increasingly on investment in thermal plant which may run with low load factors.

7. UK R&D technological capability is in niches. There is world-leading expertise in some battery and supercapacitor research which Research Councils are supporting through long-term funding, and in general, funding for energy storage has been increasing. However, the links between technology R&D and system modelling are not strong. An integrated energy storage research programme should bring these elements together.

8. The activities of the different organisations in the energy innovation landscape do not appear to be strategically aligned. In times of austerity, and the need to focus resource, this should be a priority area for coordination.

9. A number of small scale companies have grown in the UK based on energy storage technologies. But technology-push and market-pull incentives will be required to translate this into economic benefit:

   a) Scale-up to large-scale demonstration is required globally, UK could be in strong position to test and benefit from new solutions. International engagement in innovation activities should be improved to bring knowledge and value to UK economy or energy system.

   b) Cost is the main barrier now, but regulatory and 'inertia' issues will need to be overcome. Policy and regulation needs to be prepared for new business models, possibly with incentives if it can be shown to have improved carbon credentials.

10. A strategic roadmap which leads to detailed consideration of the potential role of energy storage should be drawn up covering: rigorous assessment of options by energy system models and other analyses, technology requirements, coordinated RD&D programmes, industry/supply chain needs, and regulatory/policy issues.

# Chapter conclusions

**Chapter 2 – The energy system to 2050**
The transition to the widely accepted scenario of a decarbonised and expanded power sector sees a dramatic impact on the energy system by 2030. With electricity meeting a substantial proportion of space heat and transport demand, new challenges will arise from a pronounced seasonal profile for heat demand and intermittent supplies.

These challenges can be met, and it is likely that flexible generation, greater demand side response, more interconnection and energy storage technologies will all be part of that response. The role of hydrogen is still uncertain and needs further study. Given the modest increase in costs for low load-factor thermal and nuclear plant, these will be the benchmark for provision of on-demand power.

However, the role of energy storage has been downplayed in many scenarios. It is often treated quite simplistically compared to alternatives due to the short timescales over which it can operate, its potentially distributed nature and large uncertainties over performance and cost. This gap in understanding risks driving the energy system into current market opportunities rather than potentially better long-term solutions.

**Chapter 3 – The role for energy storage**
From a high-level analysis of the future energy system examining time segments from minutes to months, we can see how energy storage can provide a functionality that would mitigate the impacts of variable supply and changing demand profiles.

The ability of energy storage to time-shift supply and demand over a wide range of energy and times scales allows such technologies to respond to many of the challenges that will arise over coming years and decades. A range of new and existing technologies could cover the challenges of supply and demand variability.

Most recent debate has been focused on providing storage for electricity supply. Mature and rapidly developing technologies will be able to provide effective frequency regulation, balancing or load levelling services over a period of hours, up to a day. With greater deployment of wind generation capacity the need for this is likely to expand.

Variability over longer timescales will become important as the wind generation capacity reaches 30GW expected in the 2020s. Covering a five-day wind lull could leave a TWh energy 'gap' in our current demand profile. It would take a much-increased volume of rechargeable energy storage in the UK and new interconnection to pumped hydro storage in Norway to offer an alternative to thermal back-up generation. There is a prospect, however, that UK energy storage volumes could be expanded through distributed thermal storage, especially if heat pumps have been widely deployed.

A future energy system that has a substantial shift from space heating by gas boilers to heat pumps would need both the generation capacity and infrastructure in place to deliver a reliable electricity supply when it is required. This could mean investment in 10sGW plant operating at low load factors, and distribution networks upgraded to meet much higher peak demands.

The total increased seasonal demand for electricity from heat pumps is of a magnitude that appears too great for storage technologies to cover for a significant proportion of the UK. To a limited extent, new buildings (commercial or domestic) may be able to use underground aquifers or heat banks charged during the summer to provide winter heating. However, over shorter timescales, a combination of electrical and thermal storage may be well-placed to cover increases in demand, or drops in supply. Alternatively, district heat networks in combination with ground source heat pumps and large neighbourhood-level thermal stores could be an option.

Energy storage may both complement and compete with other options to meet the full range of challenges that will be encountered. Each solution has its limitations: Supply from other countries though interconnection cannot be guaranteed to be available, though calling on pumped hydro in Norway could be part of a solution. Flexible generation from coal/gas plant may have a carbon penalty without investment in carbon capture technologies, which have yet to be demonstrated at scale. Operating nuclear as other than base load is untested in the UK and would need to be designed into new build. And the scale of demand side response is likely to be insufficient in scale and not available over long time periods, though the potential needs examining further.

The relative timings of increased wind power, deployment of heat pumps, roll-out of CCS, new nuclear build and commissioning of new fossil fuel plant will affect the scale and role of energy storage. With such a dynamic period ahead, further detailed analysis is needed to help plan investment in new technologies, infrastructure and generation capacity.

**Chapter 4 – Energy storage research, development and demonstration**
The need for further analysis to understand what energy storage characteristics would be most appropriate for the UK must not be a barrier to the development of some promising technologies.

An immediate priority is to demonstrate how energy storage technologies can work, both in terms of their technical performance, and as part of a system which will include consumer behaviour as a key factor in determining their effectiveness. Increasing our knowledge of operational capability and costs will feed back into analysis on the role of energy storage. Demonstrations of energy storage technologies will sit alongside (and, in many cases, be part of) similar activities for smart grids, demand side response and new generation technologies.

Underpinning R&D is needed to support the innovation process and to continue the search for incremental and step-change improvements to underlying or new technologies. The UK does have expertise in some areas, notably Li-based and flow-cell batteries. Research Councils have targeted Li-ion and supercapacitors in particular, and such a focused approach is the only way to compete on the world stage. However, the sums being spent are still relatively modest by international standards and must be directed at areas where the UK has comparative advantage.

Funding agencies spanning the innovation process need to take a coordinated and strategic approach to ensure opportunities to develop technologies in the UK are not missed. The Energy Technologies Institute does have a strong energy storage programme, but there is little currently being undertaken by the Carbon Trust and Technology Strategy Board. With a number of small UK companies active in the area, the support they could offer could be vital.

Involvement in relevant international programmes is patchy. There is some UK participation in Franework Programme projects, but no formal involvement in either IEA Implementing Agreements which concern storage technologies.

Follow-on work by ERP which marries the role of energy storage with specific technologies will consider priorities for innovation gaps in more detail.

**Chapter 5 – Deployment issues**

Energy storage is unlikely to be deployed widely under the current market framework, or those proposals being put forward under the Electricity Market Reform consultation. Development of new energy storage should be on a level playing field with other technologies. Analysis may show that it can offer strong environmental benefits by allowing the operation of low carbon generation. If this is so, there is a strong case for incentivising its deployment. Energy storage technologies should be seen as a credible option for the energy system, and recognised as such during the Electricity Market Reform process.

Commercial deployment of energy storage technologies is likely to rely on revenue from several streams, though business models are yet to be proven. These will include arbitraging across hours to peak-shave/load-shift, providing back-up capacity during low wind periods, and ensuring power supply quality. Policy-makers, regulators and potential users of energy storage should be aware of this, and not take a narrow view of what the technology can offer.

Market predictions for pre-commercial technologies are notoriously unreliable. But even an expectation that energy storage will scale-up as worldwide electricity generation expands leads to the conclusion that there will be an increase in deployment of energy storage technologies. Though this is likely to be for pumped hydro storage initially, it leaves an opportunity for new technologies.

Regulation of energy storage should be re-examined by Ofgem to ensure there are no artificial barriers to its wider deployment.

**ENERGY RESEARCH PARTNERSHIP**

58 PRINCES GATE, EXHIBITION ROAD, LONDON SW7 2PG www.energyresearchpartnership.org.uk