HOUSES OF PARLIAMENT
PARLIAMENTARY OFFICE OF SCIENCE & TECHNOLOGY

POSTNOTE

Number 492 April 2015

Energy Storage

The Government lists energy storage as one of eight great technologies in which the UK can become a global leader.[1] This briefing outlines the roles of energy storage in the electricity, heat and transport sectors and describes the technologies used from the household level up. It also discusses current barriers and policies for energy storage and potential future uptake.

Overview

- New energy storage technologies can help to maintain reliable energy supplies and could enable significant use of low-carbon electricity, heat and transport technologies.
- Cost is the main barrier for most storage. Innovation, demonstration and roll-out subsidies could address this constraint.
- For some near-cost-competitive electricity storage technologies, storage operators suggest that legislation and regulation produce significant barriers.
- There is uncertainty about the future need for energy storage outside the transport sector. However, there are several scenarios in which storage could save consumers billions of pounds cumulatively by 2050.
- Uncertainty is itself a barrier to further innovation, deployment and investment.

Background

Energy storage technologies absorb energy and store it so that it can be released when required. Fossil fuels, such as coal, oil and natural gas are forms of energy storage, having stored energy for millions of years. The use of fossil fuels has given us ready access to electricity (for example, via coal-fired power stations), heat (domestic gas boilers) and transport (petrol). However, as the UK reduces fossil fuel use, new forms of energy storage may be required, which are the focus of this briefing. Energy storage, either as electricity or heat storage, can be used in a number of ways to reduce our reliance on fossil fuels within the electricity, heat and transport sectors. These include:

- Maintaining reliable electricity supplies for national, community and household electricity systems, by ensuring that electricity supply matches demand. For example, stored electricity could compensate for lows in output from intermittent renewables, such as wind or solar (see POSTnote 464), or power plants breaking down or electricity grid failures due to problems such as flooding.
- Helping the cost-efficiency of electricity supply. This can be achieved by helping to avoid costs for electricity network expansion. One approach to avoiding network expansion involves electricity users storing electricity when demand for electricity from the grid is low. This allows users to avoid using grid electricity when demand is high, reducing the network's capacity need. Another way storage can help cost-efficiency is by allowing energy to be bought and stored at cheap off-peak rates and sold back to the grid at expensive peak times (energy arbitrage).
- Managing variations in heat supply and demand. For example, by storing the continuous low temperature outputs from heat pumps (POSTnote 426) and releasing them as short high temperature bursts, for which consumers have a preference.[2,3] In another example, the potential shift from gas to low-carbon electric heating could necessitate much more electricity generation capacity to meet winter demand; this need could be reduced by storing heat generated in the summer.[4]
- Replacing conventional transport fuels with electricity stored in batteries or low-carbon fuels. Such approaches can produce lower greenhouse gas emissions and air pollution (POSTnote 458).

A future energy storage sector that uses a combination of these approaches could save UK consumers billions of pounds and contribute further billions to GDP.[5] However, the size of these benefits is uncertain (see section on uncertainty and future energy storage).

Energy Storage Technologies

Energy storage technologies can be divided into those that absorb electrical energy and those that absorb heat energy. (Cold storage, for example through the storage of cold liquids, is outside the scope of this briefing.)

Electricity Storage Technologies

The following technologies can be used for stationary storage and some can also be used in transport.

- **Pumped hydroelectricity storage** (PHS) involves pumping water up to a reservoir; when electricity is needed it is released through turbines. PHS is suited to large-scale applications to manage variations in electricity supply and energy arbitrage. PHS makes up over 99% of UK and global grid-scale electricity storage.[6] The UK has roughly 2,800 Megawatts (MW) of PHS capacity (peak UK electricity demand was 52,000 MW in 2013), mostly built from 1963 to 1984 by the national electricity boards. While this storage is still used, PHS has found it difficult to compete for investment in new plants since privatisation. PHS suffers from geological restrictions, limiting the locations where they can be built. However, Quarry Battery has plans to open a 100 MW PHS site near Bangor in 2018.
- **Compressed air energy storage** (CAES) involves storing air at high pressure, often underground, before using it to generate electricity via a turbine. It is suited to large scale applications, but also has some geological restrictions. Gaelectric are exploring the potential for a UK CAES unit.
- **Pumped heat electricity storage** involves pumping heat away from a cold, gravel-filled container into a hot one. Reversing this drives a pump, which generates electricity. Isentropic Ltd is developing the technology.
- **Liquid air energy storage** involves cooling air to temperatures below -196ºC, where it turns into a liquid. When heat is reintroduced, it gasifies, expands and turns a turbine. In 2015, Highview Power is due to open a 5 MW demonstration plant near Bury for grid-scale applications. Liquid air can also provide cooling directly.
- **Battery storage** technologies include lead-acid, lithium-ion and sodium-sulphur designs. Sodium-sulphur batteries are suited to grid-scale applications, while lithium-ion batteries are also used in electric vehicles. The local network operator UK Power Networks is trialling a 6 MW lithium-ion battery in Leighton Buzzard from 2013-2016. An alternative technology to conventional batteries is flow-cell battery storage, which stores energy in liquids.
- **Hydrogen** stores energy that can be released by burning it or through a fuel cell chemical reaction. The hydrogen can be produced by using electricity to split it from the oxygen in water molecules. It can be stored in units in the household, vehicles or at a larger scale. ITM Power is exploring the potential to inject it into the UK gas grid.[7,8]
- **Flywheel and Supercapacitor** technologies can deliver power rapidly but have limited storage capacity. They can be used to recover energy from braking in cars and trains or to ensure that power for large energy consumers is not interrupted by providing short bursts of backup electricity.

Heat Storage Technologies

There are three categories of heat storage technology.

- **Sensible heat storage** technologies simply store heat in a solid or liquid, without causing it to change state.
- **Latent heat storage** materials store energy as they undergo a change of state, generally from solid to liquid.
- **Thermochemical heat storage** stores heat by bonding chemicals together which release heat when separated.

For daily storage, sensible heat storage technologies are already widely used in buildings through electric storage heaters and hot water tanks.[9,10] Hot water tanks store heat from traditional gas boilers and more recently solar thermal systems. One problem with hot water tanks is that they require space for a large tank, which has led to a decline in the number of tanks and may limit their future use to larger properties.[11] Latent and thermochemical heat storage technologies don't have the same space constraints.[12] Some forms of latent heat storage have been introduced to the market but they are not yet widespread in the UK.[13] Thermochemical heat storage is at the early stages of research and development.[14]

For inter-seasonal storage of large amounts of heat, sensible storage can be used. For example, heat can be stored in underground water aquifers, in the rock surrounding boreholes or in tanks of around 10,000 litres filled with water or gravel. These technologies are used for inter-seasonal heat storage in other countries.[15]

Challenges to Further Uptake

Cost of Energy Storage

Most experts agree that cost is the main barrier to large-scale uptake of most storage technologies, with the exception of heat storage in buildings.

Stationary Electricity Storage

Electricity storage units currently have large up-front costs, which take many years to recover. In addition, large-scale storage units compete against fuel-burning power plants, electricity from overseas electricity grids and demand-side response (see POSTnote 452) to provide flexibility in the level of electricity supply or demand. Small-scale electricity storage competes against small diesel-fuelled electricity generating units and the use of flexible grid electricity. Some electricity storage technologies can perform certain roles at or near the same cost as alternatives (see Box 1), but most are more expensive.[16] Even where electricity storage is currently cost competitive, investment in new storage is not certain because the potential for the market to change quickly can discourage investors.[17]

Storage for Transport

Battery cost is the largest cost in the production of battery-only electric road vehicles. To make battery-only vehicles cost competitive with average priced cars, smaller batteries are used, with a driving range of 60-100 miles.[18] Surveys of UK car drivers show that this, coupled with sparse charging stations and long charging times, is a major barrier to widespread adoption of battery-only electric vehicles.[19]

Box 1. Financial Viability of UK Electricity Storage Development

In the UK, only small volumes of electricity storage capacity have been built since the 1980s.[20] The financial viability of new energy storage projects depends on the return storage can attract (either in terms of revenue or cost reductions) and the cost of buying and operating storage. These differ depending on the payments available from each country's electricity market and the local cost of energy storage (for example, the cost of PHS and CAES vary according to the suitability of local geology). Understanding which technologies and applications could be financially viable in the UK, or close to viable, has been the subject of number of studies.

- Bloomberg New Energy Finance (BNEF) found that using Lithium-ion battery storage to avoid electricity network upgrades in certain locations could be cost neutral.[21] However, there are regulatory issues with network operators using storage for this application (see section on legislative, regulatory and commercial barriers).
- There are differing evaluations of the viability of building new storage to provide National Grid with reserves of supply, known as balancing services. National Grid concludes that new CAES would cover its costs by providing one balancing service, while other technologies need further cost reductions.[22] BNEF argues that providing single balancing services is not profitable for storage, but that providing multiple balancing services may be profitable.[23] However, there are barriers to providing multiple services (see section on legislative, regulatory and commercial barriers).

Where range is not a barrier for consumers (for example, where the electric vehicle is used as a second car), the overall cost of owning a battery-only electric vehicle for four years can be competitive with conventional vehicles, under current subsidy schemes.[24] However, the high up-front price of battery-only vehicles remains a barrier. Hybrid vehicles (part-battery part-petrol) manage the issues of range and up-front costs with differing levels of dependency on the battery. The least battery dependent versions are now fully commercial, while the more battery dependent versions receive subsidies. In 2014, UK sales of plug-in hybrid (higher battery dependency) or battery-only vehicles quadrupled to 14,500.[25] Hydrogen-fuelled vehicles have been introduced to the UK-market in very limited numbers and are expensive compared to conventional vehicles.

Legislative, Regulatory and Commercial Barriers

There are interrelated legislative, regulatory and commercial barriers to grid-scale electricity storage. Legislation and regulation treat storage either as generation or as an electricity end-user (Electricity Act 1989 and EU Directives).[26] Industry suggests that this leads to private storage facilities being charged too much by the regulated network operators and energy suppliers (see Box 2) and it makes it difficult for network operators to use storage to help avoid electricity network expansion and its associated costs (see Box 3). The latter might otherwise provide an earlier, economically viable route to market for grid-scale electricity storage (see Box 1).

Among commercial issues, storage operators have found it difficult to arrange contracts for multiple services, for example, one to offer backup electricity supplies and one to help avoid network expansion.[27] This difficulty can restrict revenues and reduce the viability of storage. The problem can arise because the contracts offered by network operators to ensure stable electricity supplies sometimes limit which other contracts storage operators may sign.[36] Although this is designed to ensure that the contract commitments are always delivered, storage operators suggest there is often potential to deliver on more than one contract.[37,38] It is also expensive for small operators to develop a number of contracts, which are often bespoke.

Box 2. Overcharging for Storage?

Stakeholders identify two areas where storage may be overcharged.

- Storage is charged for connecting to the local or national electricity networks in the same way as electricity generation facilities. Storage operators suggest that storage should be charged less, or even paid, for connection as storage may reduce network operators' costs, in contrast to generating facilities.[28] Network operators suggest that the savings are dependent on how the storage is operated. They argue that contracts need to be in place to ensure cost-saving operation. However, there has been limited effort to develop these contracts.[29]
- UK Power Networks (UKPN) suggests that storage should not be subject to some green levies (such as the levelisation charge for the Government's feed-in-tariff scheme[30]) because storage is not an electricity end-user. UKPN suggests that charging these fees disincentivises storage and end-users effectively pay the fee twice on electricity that reaches them via storage.[31]

Box 3. Limitation on the Role of Network Operators

Under the Electricity Act 1989 and Electricity Directive 2009/72/EC, the local and national electricity network operators are not permitted to control the sale of electricity to consumers.[32] This is designed to prevent network operators entering the electricity market and competing with private providers of storage, which is considered undesirable as the network operators have the advantage of being regional monopolies.[33] However, industry is concerned that the restriction makes it difficult for the financial benefit of avoiding network expansion to be realised.[34] UK Power Networks (UKPN) is trialling an approach where the network operator uses storage. In the trial, UKPN controls when storage discharges and charges for network purposes, while interaction with the electricity market is carried out by a private third party. It is not clear whether this approach, or alternatives, could be used beyond this trial, without a change to legislation.[35]

Energy Storage Policy

Governments around the world are supporting energy storage programmes. For instance, the Japanese and German governments are funding subsidy programmes, while the Californian authorities have imposed an obligation to invest in 1,300 MW of energy storage on the State's three biggest utility companies. In the UK, the Government has a range of policies that support energy storage (Box 4).

There is debate about which policies are needed to support energy storage. The industry body, the Electricity Storage Network, argues that electricity storage should receive support for larger-scale deployment, to reduce costs in anticipation of the potential future need.[39] The House of Lords Science and Technology Committee has recommended that the Government examine whether electricity storage should be placed under the Contracts for Difference regime (which pays many low-carbon generating technologies above the market price for electricity) rather than the Capacity Market (Box 5), which pays participants

Box 4. UK Energy Storage Support
The Government is supporting storage through the following policies.

Electricity and Heat R&D and demonstration
Public bodies including the Engineering and Physical Sciences Research Council, Energy Technologies Institute, Ofgem, Department of Energy and Climate Change and Innovate UK each have programmes funding electricity and heat storage development with multi-year budgets from millions to tens of millions of pounds.[40,41] In 2013, public sector energy storage spending on R&D was £9m and on demonstration £5m.[42] Research and development (R&D) spending aims to develop lower cost technologies, while demonstration spending is also looking to tackle regulatory and commercial barriers.

Transport Sector Policy
Energy storage in transport is not directly supported, but there are policies to support lower carbon vehicles. EU regulation sets targets to reduce CO_2 emissions from new UK passenger cars by 2020 by 26% from 2013 levels.[43,44] The 2010-2015 Government committed to spending £500m on low-emission vehicles over 2015-2020, of which £200m is on grants to increase vehicle uptake (including car and van grants of up to £5,000 and £8,000) and £100m on R&D.[45] There are also regional policies offering benefits to low carbon vehicles such as free parking.

near to the market price and is unlikely to support new projects in the near-term.[46] Bloomberg New Energy Finance suggests that cost-reducing support is not needed for all stationary electricity storage technologies because some are deployed at scale in other countries, and that more concentration on possible changes to regulation and legislation may bring forward early projects. The debate is affected by uncertainty about forecasts that may be used to justify support for energy storage, such as the future amount of energy storage and the magnitude of the associated future benefits.

Uncertainty and Future Energy Storage
The amount of future energy storage deployment is uncertain. It is also unknown if one or two technologies will dominate, or whether there will be a mix of technologies for different uses. Most observers agree that storage will become more economically viable as fossil-fuel-based alternatives become less competitive because of policies to reduce greenhouse gas emissions and long-term rising fossil fuel prices. Capital costs of storage technologies may also decrease. Other factors also influence the viability of each storage sector.

Stationary Electricity and Heat Storage
The future of stationary electricity and heat storage depends on how and when the low-carbon energy generation mix will change. Demand will increase for flexibility from stationary electricity storage in scenarios with high proportions of intermittent renewable and inflexible nuclear electricity generation. Scenarios with higher levels of flexible fossil-fuelled generation combined with carbon capture and storage will lead to lower demand for electricity storage.[47] Even in high renewables scenarios, electricity storage will still need to compete on price against competitors, such as electricity from overseas. Levels of household or community scale electricity storage will depend partly upon whether owners of small-scale generation, wish to be independent from the grid. For heat storage, demand will increase with increasing numbers of heat pumps. Given these dependencies, energy sector groups pose a wide range of plausible scenarios for the future amount of energy storage, from very little new storage to tens of thousands of megawatts.[51,52] In a mid-range scenario the Low Carbon Innovation Co-ordination Group suggests successful innovation could lead to:

- 9,000 MW of grid-connected electricity storage by 2020 and 27,000 MW in 2050. In this scenario the energy system (and ultimately consumers) could save £4bn cumulatively by 2050, with the UK industry contributing an estimated £11.5bn to GDP over that period.[53]
- 1,800 MW of heat storage in 2020 and 45,000 MW by 2050.[54] In this scenario, successful innovation could save the energy system £3bn cumulatively by 2050, and at least another £3bn by encouraging consumers to use heat pumps.[55]

Box 5. The Capacity Market
The 2013 Energy Act established the Capacity Market, which offers regular payment to organisations that can guarantee to supply electricity when required.[48] The market offers a potential source of revenue to electricity storage alongside markets that are organised by National Grid to ensure the second-by-second balance between electricity supply and demand. Competition for the limited Capacity Market revenue is via an annual auction, which does not favour any particular technology. The first auction took place in December 2014. Existing electricity storage accounted for 5% of the total capacity awarded; no new storage projects received support.[49] In addition to the main auction, an additional 'transitional' auction will run in 2015 and 2016 to help smaller (<50 MW) localised generation, electricity storage and demand-side response to build capacity.[50] The Electricity Storage Network says that it is unlikely that the additional auctions will incentivise new storage construction because of the short one-year contracts and competition from small diesel-fuelled generation units.

Storage for Transport
There is more confidence about the future of electricity storage in transport, with few low-carbon alternatives available; the main alternative is biofuels (see POSTnote 410). In the short term it is expected that hybrid vehicles will gain market share as EU CO_2 emission restrictions tighten.[56] However, there is still uncertainty about the timing of growth of battery-only electric vehicles and hydrogen-fuelled vehicles, with European vehicle emission targets beyond 2020 yet to be set. Element Energy estimates that without support measures the high up-front price of battery-only vehicles will remain a barrier to large-scale uptake until at least 2030.[57]

Endnotes

1 https://www.gov.uk/government/publications/eight-great-technologies-infographics
2 UK Energy Research Centre, 2014, The Future Role of Thermal Energy Storage in the UK Energy System: An Assessment of the Technical Feasibility and Factors Influencing Adoption
3 Low Carbon Innovation Coordination Group, 2012, Technology Innovation Needs Assessment Heat Summary Report
4 Centre for Low Carbon Futures, 2012, Pathways for Energy Storage in the UK, page 10
5 Low Carbon Innovation Co-ordination Group, February 2014, Coordinating Low Carbon Technology Innovation Support: The LCICG's Strategic Framework, page 64

6 International Energy Agency, March 2014, Technology Roadmap: Energy Storage, page 17
7 H2FC Supergen, May 2014, The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat
8 ITM Power, National Grid, Shell, SSE, Scotia Gas Networks, Kiwa, et al. Power-To-Gas: A UK Feasibility Study. ITM Power Plc, Sheffield; 2013.
9 Institution of Mechanical Engineers, April 2014 Energy Storage: The Missing Link in the UK's Energy Commitments, page 35
10 Energy Research Partnership, June 2011, The Future Role for Energy Storage in the UK, page 9
11 Low Carbon Innovation Coordination Group, 2012, Technology Innovation Needs Assessment Heat Summary Report
12 Institution of Mechanical Engineers, April 2014, Energy Storage: The Missing Link in the UK's Energy Commitments, page 36
13 UK Energy Research Centre, 2014, The Future Role of Thermal Energy Storage in the UK Energy System: An Assessment of the Technical Feasibility and Factors Influencing Adoption, page 2, 27 and 29
14 UK Energy Research Centre, 2014, The Future Role of Thermal Energy Storage in the UK Energy System: An Assessment of the Technical Feasibility and Factors Influencing Adoption
15 UK Energy Research Centre, 2014, The Future Role of Thermal Energy Storage in the UK Energy System: An Assessment of the Technical Feasibility and Factors Influencing Adoption
16 Bloomberg New Energy Finance, January 2012, Energy Storage Valuation study: UK, page 7
17 Low Carbon Innovation Co-ordination Group, February 2014, Coordinating Low Carbon Technology Innovation Support: The LCICG's Strategic Framework, page 62
18 Which, accessed January 2015, http://www.which.co.uk/cars/choosing-a-car/eco-cars/electric-and-eco-cars-guide/electric-cars-range/
19 Element Energy, December 2013, Pathways to High Penetration of Electric Vehicles
20 Institution of Mechanical Engineers, April 2014, Energy Storage: The Missing Link in the UK's Energy Commitments, page 19
21 Bloomberg New Energy Finance, January 2012, Energy Storage Valuation study: UK
22 National Grid, July 2014, Future Energy Scenarios, page 120
23 Bloomberg New Energy Finance, January 2012, Energy Storage Valuation study: UK, page 1
24 Element Energy, December 2013, Pathways to High Penetration of Electric Vehicles
25 Society of Motor Manufacturers and Traders, accessed 22nd January 2015, http://www.smmt.co.uk/2015/01/uk-automotive-2014-review/
26 Poyry, July 2014, Smarter Network Storage Low Carbon Network Fund, Electricity Storage in GB: Interim Report on the Regulatory and Legal Framework
27 Personal communication, IEA, University Birmingham, Energy Technologies Institute
28 Personal communication, Quarry Battery
29 Personal communication, UK Power Networks
30 http://www.endco.co.uk/market-information/industry-charges/, accessed 24th Febraury 2015
31 Personal Communication, UK Power Networks
32 Smart Grid Forum, April 2014, Work Stream Six Interim Report – Appendix 2
33 Smart Grid Forum, April 2014, Work Stream Six Interim Report – Appendix 2, page 42
34 Personal communication, EDF Energy
35 Personal communication, Ofgem and UK Power Networks
36 Personal communication, UK Power Networks
37 Energy Networks Association, April 2014, Demand Side Response Shared Services Framework Concept Paper, For Industry Consultation
38 Energy Networks Association, November 2014, Demand Side Response Shared Services Framework Concept Paper, Consultation Response
39 The Electricity Storage Network, 2014, Development of Electricity Storage in the National Interest
40 EPSRC, accessed December 2nd 2014, http://www.epsrc.ac.uk/research/ourportfolio/researchareas/energystorage/
41 House of Commons Library standard note, Energy Storage R&D, http://www.parliament.uk/briefing-papers/SN06936/energy-storage-rd
42 DECC submission to IEA
43 Calculated based on The Society of Motor Manufacturers and Traders Limited, 2014, New Car CO2 Report
44 European Commission, accessed 5th January 2015, Reducing CO2 emissions from Passenger Cars
45 https://www.gov.uk/government/news/deputy-prime-minister-takes-green-cars-up-a-gear
46 House of Lords Science and Technology Committee, March 2015, The Resilience of the Electricity System
47 Imperial College London, June 2012, Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future, page 15
48 DECC, accessed 5th January 2015, Electricity Market Reform: Capacity Market
49 National Grid, Jan 2015, Final Auction Results
50 DECC, September 2014, Electricity Market Reform: Capacity Market: Consultation on Capacity Market Supplementary Design Proposals and Transitional Arrangements
51 National Grid, July 2014, Future Energy Scenarios
52 Low Carbon Innovation Coordination Group, August 2012, Technology Innovation Needs Assessment (TINA): Electricity Networks and Storage Summary Report
53 Low Carbon Innovation Co-ordination Group, February 2014, Coordinating Low Carbon Technology Innovation Support: The LCICG's Strategic Framework, page 64
54 Low Carbon Innovation Co-ordination Group, February 2014, Coordinating Low Carbon Technology Innovation Support: The LCICG's Strategic Framework, page 64
55 Low Carbon Innovation Coordination Group, 2012, Technology Innovation Needs Assessment Heat Summary Report, page 8
56 Automotive Council UK, 2013, Automotive Technology Roadmap
57 Element Energy, December 2013, Pathways to High Penetration of Electric Vehicles