ERP DRAFT REPORT:

Barriers to System-Wide Energy Storage

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1 Executive Summary

Energy Storage is an inherent part of the UK's energy system, providing key system services and benefits such as: flexibility, resilience and system security. Fossil fuels currently offer large volumes of long duration storage over periods of months, with other more 'invisible' forms of storage e.g. domestic hot water tanks, also providing valuable capabilities that are often overlooked. These feasible and economic storage solutions are already in existence, but are not always fully recognised and are at risk of being lost.

Changes to the energy system are affecting the types of storage available, such as the phasing out of coal, plus the future role of natural gas and whether it can be decarbonised. Additionally, new challenges are being created, through increasing levels of renewable technologies and the potential electrification of heat and transport.

The key challenges created are therefore how to replace the existing high-value, low-cost storage solutions that are already offered, whilst providing the services that accommodate daily fluctuations and peaks, in addition to variations over several weeks, months or seasons. This must be achieved in a cost appropriate way, with system-wide benefits.

Storage is not an end its own right and covers a wide range of applications. It is noted that alternative options such as Demand Side Response (DSR), Interconnection, increased Flexible Generation, the role of Networks (e.g. Active Network Management (ANM)), plus the potential use of Hydrogen, can also help provide the above noted system services that are increasingly required as changes to our energy system occur.

Following assessment of the current situation in relation to storage, plus the above alternative options and the potential value that storage can add, a range of barriers are highlighted that currently prevent the uptake of system-wide energy storage solutions. Of significance is that an integrated system approach is needed to ensure electrical, thermal, natural gas storage options, and other solutions, are able to provide services and benefits across the energy system, with equal access and on a level-playing field.

Key Messages & Recommendations

System-Level / strategic messages:

Barrier 1: Externality benefits and missing markets

System-wide Energy Storage assets offer a range of services and solutions such as energy security, resilience and flexibility that can help mitigate risk (i.e. create benefits) for society. These services are currently undervalued or are not yet fully accounted for within existing market frameworks.

Recommendation 1:

Clarity from policy-makers regarding the required levels of these services, with associated system 'metrics' and newly created mechanisms would help stimulate markets in these areas. This would allow storage (and other solutions) to compete on a level-playing field, whilst ensuring these services are valued appropriately at both the system and individual asset, or community, levels.

Barrier 2: Lack of clarity regarding the role of storage

There is the need for a more strategic, impartial consideration of the potential future role that storage can play across the UK's energy sectors. Improved alignment of activities, plus a clearer whole-system direction (as above), would help characterise and value system services whilst encouraging storage to compete alongside other alternatives.

Recommendation 2:

An organisation with capabilities and the responsibility for designing, advising on and facilitating the UK energy system from a whole-system perspective is recommended. This role should be provided by a dedicated independent or government body and should include the assessments of services and technologies that provide benefits and solutions across the three key sectors of energy: power, heat and transport.

The Future Power System Architecture Project (FPSA) project commissioned by DECC[1], is likely to help provide further details of the type of organisation required. It is important that any such body should focus on alignment of services and solutions across the whole energy system however i.e. not focus solely on the power sector.

Storage-related messages:

Barrier 3: Regulatory - Missing markets

Existing regulatory frameworks do not consistently provide clear signals and opportunities for system-wide storage projects that can provide cross-sector solutions. Where there *are* clear signals of the need for storage, a range barriers exist that can prevent the service from progressing or being adopted. Two main options for addressing this are: i) provide energy storage with its own dedicated treatment (e.g. subsidies, tax breaks, a legal definition) and/or its own regulatory framework ii) adapt the existing regulatory framework to promote a level-playing field and remove the disadvantages currently faced (e.g. double-charging for electrical storage).

Recommendation 3:

ERP recommends that the current system should be adapted to allow storage to operate (and compete) without being disadvantaged, as opposed to providing special treatment. However, some aspects such as a clearer legal definition need to be addressed. It is noted that a truly flexible and resilient energy system or market, with a clear direction, should be able to successfully accommodate and incorporate energy storage services that serve key system needs. This should remove many of the requirements for special treatment.

ERP additionally recommends a deeper consideration of the *whole-system* need for storage, the value that various storage services or technologies can provide and whether these are currently disadvantaged compared to other options. This would help make decisions regarding dedicated treatment required and could be carried out by an organisation such as the Energy Systems Catapult.

Barrier 4: Financial - failure to recover long-run marginal costs

There is no shortage of available capital and a keenness to invest in energy system projects and assets (including storage) if the risks are well understood and manageable. However, there is a shortage of *risk-capital* and a lack of certainty to help fully inform investment decisions regarding i) the opportunity and breadth of storage projects available and ii) the risks of investing. Aspects such as the value of services that storage provides, volatility of associated revenues and the potential mismatch of duration risk (i.e. the forward visibility of contracted revenues being less than the timescale of returns for asset finance), currently hinder many projects from being financed.

Recommendation 4:

Creating conditions of greater certainty for investors by addressing the barriers noted above will help unlock the cheaper 'debt' (as opposed to pricier 'equity') finance required. This in turn will enable a greater number of storage projects to become commercially viable. Options to address this include: i) provide greater certainty to enable more informed investment decisions with information tailored towards the finance industry; ii) the introduction of third parties to help underwrite the associated risks; iii) improvements to regulatory systems to help ensure the lowest cost of capital.

[1] undertaken via a collaboration between the Institute of Engineering and Technology (IET) and the Energy Systems Catapult (ESC)

Barrier 5: Commercial – rules and regulations

Key commercial risks apply particularly when considering storage as an additional or retrofit service to be added to sites with pre-existing infrastructure and commercial arrangements. These can hinder the uptake or deployment of some specific storage types.

Recommendation 5:
Various options to address this fall into: technical amendments per site; reduction of risk via third party underwriters and improved regulatory arrangements to reduce perverse outcomes.

2 Introduction & Background

Energy Storage is an inherent part of the UK's energy system that provides key services and benefits such as flexibility, resilience and system security. Fossil fuels currently offer large volumes of long duration storage over periods of months, with other more 'invisible' forms e.g. domestic hot water tanks, also providing valuable capabilities that are often overlooked. Feasible and economic storage solutions are therefore already in existence but are not always fully recognised and are at risk of being lost.

New challenges for maintaining and replacing storage assets at various scales are being created by changes to the energy system. Increasing levels of renewable technologies, electrification of heat and transport, the phasing out of coal, the potential use of Hydrogen, and the future role of natural gas and whether it can be decarbonised, will all affect the future levels and types of storage.

The key challenge is therefore how to replace the existing high-value, low-cost storage solutions that are already offered, whilst providing the services that accommodate daily fluctuations in addition to variations over several weeks, months or seasons. This must be achieved in a cost appropriate way, with system-wide benefits and control.

This report considers storage as a system-wide service, available in a variety of forms. Although important to recognise, this viewpoint can admittedly add to the already complex task of assessing storage services that compete in a range of markets with a range of associated barriers and benefits.

A recent report by The Carbon Trust et al (2016) considered the question *'Can storage help reduce the cost of a future UK electricity system?'* and delivered findings that storage can enable a system wide saving of up to **£2.4bn a year by 2030.** The report highlights some core barriers relating to two storage examples (Wind and PV) and makes recommendations for how to overcome these. This work therefore provides a useful basis for the *electricity* storage aspects of this report. However as noted, ERP's work looks at storage services beyond this, across the whole energy system. Other recent reports such as those by The World Energy Council (2016) and The National Infrastructure Committee (2016), are also of relevance.

2.1 Scope of the report

This report provides a system-wide overview of the current *financial, legal, political, commercial and regulatory* challenges for Energy Storage deployment to 2030. The work highlights significant barriers and puts forward recommendations and solutions for how energy storage applications can be appropriately enabled and utilised across the UK's key energy sectors.

The report begins by considering the existing situation, the whole system need for storage and potentially competing services. The value of storage, business models and the UK market are then also discussed before moving on to identify system-wide barriers to Energy Storage and possible ways to overcome them. This identification of barriers will be of value to policy-makers, regulators, network operators, customers, investors & ES developers (technology & supply chain developers) and where appropriate, the work will help catalyse and mobilise investment in an Energy Storage supply chain of value to the UK, particularly where there is a market need. This will be achieved by enabling collaboration and discussion between the parties and actors that are key to the system-wide development and deployment of Energy Storage and by presenting examples of energy storage options.

The majority of research for this report has been informed by workshops and interviews with a range of experts from across the energy system, plus secondary analysis and synthesis of relevant reports.

3 Storage Options

Storage incorporates a wide range of applications at various levels of power vs duration and single or multiple charge/discharge cycles. The suitability of storage solutions per situation therefore need to be assessed across: cost, lifetime, energy, power, size, weight and efficiency factors. Existing storage options tend to be cheaper with longer lifetimes e.g. pumped hydro at a cost of £112/kWh[2] with a 60 year lifetime and 73% efficiency. More novel forms of storage e.g. Li-ion batteries have a much higher cost of ~£376/kWh with a 3-10 year lifetime, although an efficiency of >90% depending on use.

Figure 1 presents rated capacity vs discharge time duration at rated power for a range of system-wide energy storage technologies and assets. Mature, commercialised stage technologies (blue boxes), or those at the demonstration and development stage (green boxes), are shown in relation to their potential to address a variety of UK system challenges (in orange).

Many energy storage options within the chart are currently clustered in the lower left-hand corner i.e. smaller capacity, shorter duration. As the longer duration area (bottom-right), or higher capacity & longer duration area (top-right) is reached, system challenges increase in number with fewer storage solutions.

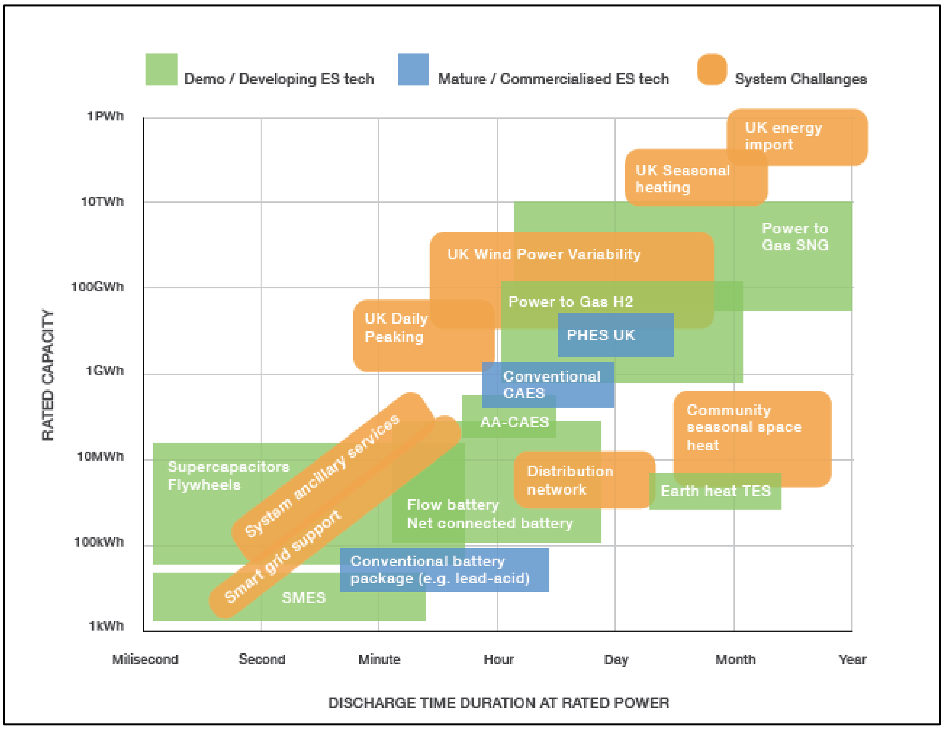
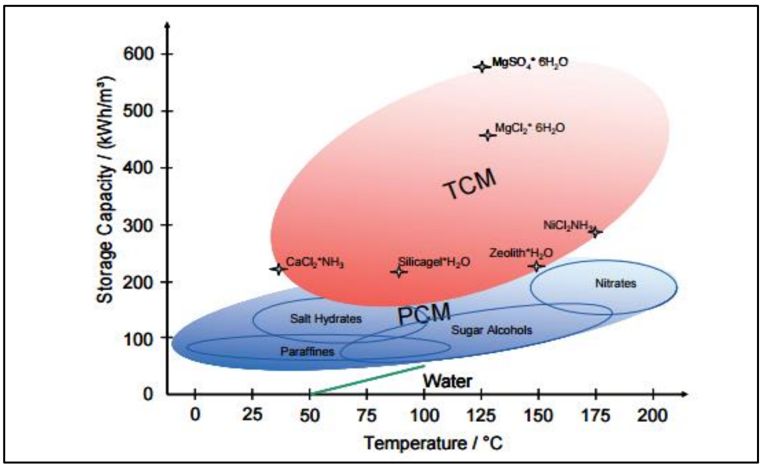


Figure 1: Energy Storage Technologies with potentials to address UK system challenges. Adapted from Luo (2015).

2 Figures from ECI, Oxford University (2016)

Figure 2 presents a similar diagram of the capabilities of thermal energy storage (capacity vs temperature) for Sensible, Latent (Phase Change Material (PCM)) and Thermochemical (TCM) types.

Figure 2: Storage Capacity vs. Temperature for Thermal Energy Storage types; Source IRENA (2013)



Box 1: System-Wide Energy Storage: myths debunked

☒ Energy Storage is a technology.

☑ Energy Storage is not a technology. It is a system service or asset that consists of individual storage technologies e.g. Li-ion batteries, CAES, phase change heat batteries. It is also however related to the storage of vectors such as natural gas and hydrogen.

☒ Energy storage purely refers to electrical storage.

☑ Although there is much excitement around the potential of electrical storage currently; as highlighted within this report, energy storage should be considered more widely as a service across electricity, heat, natural gas, hydrogen, transport and other less-known forms e.g. marine/off-shore storage.

☒ There are no suitable sites left for Pumped Hydro assets to be of significant benefit to the UK.

☑ A range of suitably sized pumped hydro sites remain and have been identified by UK utilities that could add to system flexibility, resilience and security. The majority of these are in Scotland, UK and could provide large levels of capacity (30 MWh / 600MW) in addition to important grid balancing services. Revenue could also be earned via arbitrage. However Pumped Hydro is very much dependent on height, location and other factors that affect the economic viability of these schemes.

☒ The UK's Rough Natural gas Storage facility off the East Coast of England is enough **alone** to supply the UK for 9 days.

☑ The Rough Natural gas Storage facility can provide 9 days (3.31 billion cubic meters) of natural gas storage and can provide 10% of the UK's peak natural gas demand. However in reality, this is a half-myth as the UK would never depend on only one natural gas storage asset due to lack of system security reasons.

Note to Members: further myths are to be added

4 The need for system-wide Energy Storage

4.1 The current situation

A range of existing storage types are provided in figures 3-9 below. These consist of pumped hydro electrical storage, thermal, natural gas and hydrogen storage and storage in transport.

4.1.1 Pumped Hydro Electrical Storage

Scheme status	*Name*	*Power (MW)*	*Energy Capacity (GWh)*	*Duration of storage (hrs)*
Operational	Dinorwig	1,728	9.1	5
	Cruachan	440	10	23
	Festiniog	360	1.3	4
	Foyers	300	6.3	21
Projects with full Statutory planning consent awaiting investment decisions	Coire Glas	300-600	30	50-100
	Sloy *(conversion)*	60	1	17
	Glyn Rhonwy	100	1.2	12
Projects proposed awaiting submission to the planning process	Balmacaan	300-600	30	50-100
	Cruachan *(upgrade)*	440-600	7.2	12-16
	Glenmuckloch	400	TBD	TBD
	Muaitheabhal	150	TBD	TBD
Projects at Feasibility stage	Foyers *(upgrade)*	300	4	13

Figure 3: UK Pumped Hydro sites; Source: Map from Carbon Brief (2016); Table courtesy of SSE

Pumped Hydro Energy Storage (PHES) is an existing dominant form of storage within the UK (0.03 TWh) and globally provides ~99% of the world's electricity storage. Four of the most sizeable pumped hydro sites are shown in figure x, associated with the larger circles on the map; with all sites (including non-pumped hydro) shown in the same diagram. These larger Pumped Hydro sites provide capacity and system security, and help balance the grid at times of peak demand. Between 7-13 additional sites of suitable scale, largely in Scotland and Wales, have been identified for potential planning and development. Suitability will depend on a range of factors including location, head height (distance between upper and lower reservoirs), economic feasibility and political clarity regarding the value of pumped hydro for the future UK energy mix. The System Operator has noted that no new large-scale pumped-hydro schemes are likely before 2026.

4.1.2 Battery Electrical Storage

Figure 4 presents the latest comprehensive listing of UK grid-connected (both transmission and distribution) energy storage projects. This list identifies 20MW of grid-connected capacity commissioned in the UK - most of which is provided by a 6 MW and 10MW lithium-ion battery system in Leighton Buzzard, owned by UK Power Networks and AES.

Electrical storage schemes also exist on smaller scales for off-grid island applications such as the Shetlands in Scotland and there is currently great interest in this form of storage as a complimentary solution alongside renewables (such as wind and solar), smoothing variability and assisting with grid services.

In relation to grid services, installed capacity of electrical energy storage is set to increase significantly following National Grid's spring 2016 tender for 200 MW of Enhanced Frequency Response capacity. Based on the first auction for these services, battery systems (and flywheels) have notably come forward as having the speed of response needed to provide them.

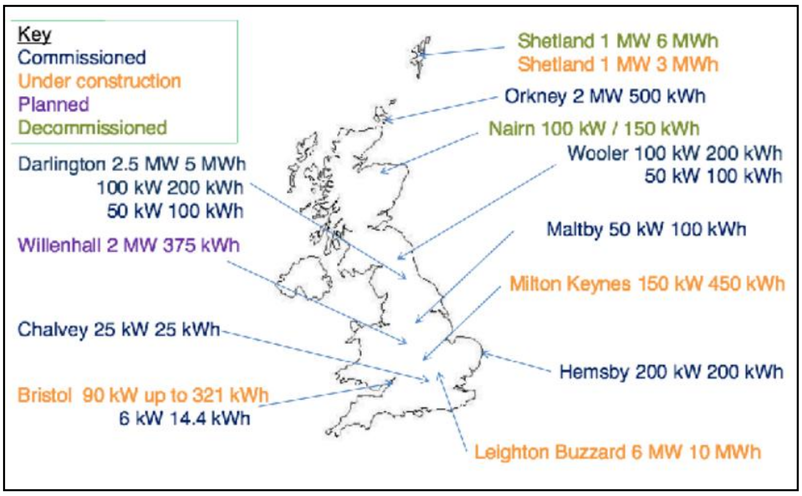
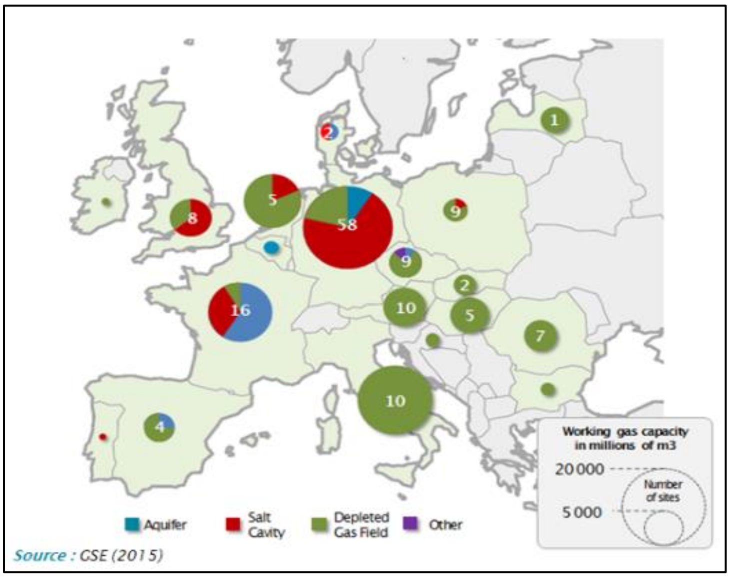


Figure 4: UK Grid-connection energy storage projects Source: Energy Storage Operators' Forum

4.1.3 Natural Gas Storage

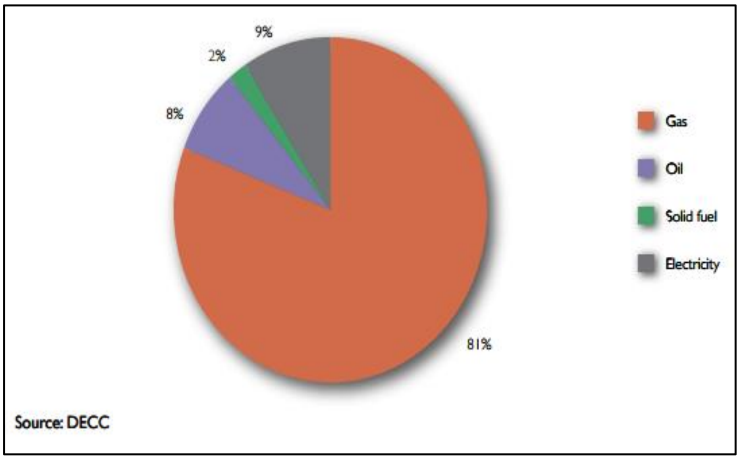


Fossil fuels (and associated grids) currently provide high density, low capital cost storage solutions. With plans to phase out coal for electricity generation by 2025 (which currently provides the largest UK storage capability of up to 158 TWh), much of the UK's future system storage capability will rely on natural gas (currently at a relatively lower level of storage of 45 TWh).

Figure 5: Underground working natural gas storage capacities across the UK and Europe, in millions of cubic meters (m3); Natural gas in Focus (2015)

A predominant use of natural gas currently, is that it satisfies 80% of the UK's heat demand (figure 6), although various sources stress that decarbonisation of the natural gas grid (and therefore of heat) are vital for achieving the UK's decarbonisation targets. Natural gas also provides the most common fuel source for Combined Heat and Power (CHP) plants.

Figure 6: Breakdown of current heating systems across all UK buildings; DECC (2012)



The future role of (decarbonised) natural gas is additionally discussed within energy scenarios alongside increasing renewable penetrations, to provide a stable baseload that compliments the variable nature of renewable energy types such as solar and wind.

With indigenous supplies in sharp decline, the UK is increasingly reliant on imports, exposing it to security of supply concerns and potential price shocks. A recent report by EUA Utility networks (2016) states: "By 2020 60% of the UK natural gas supply is set to be imported, rising to 90% in 2035".

Although not large compared to levels of natural gas storage within a number of other countries (see figure 5), natural gas storage is currently a large and reliable form of energy storage within the UK - providing flexibility, system security and resilience.

4.1.4 Thermal Energy Storage & the seasonality of heat

Thermal storage is available in three key forms**:**

1. **Sensible heat storage** - based on storing thermal energy by heating or cooling a liquid or solid storage medium (e.g. water, sand, molten salts, rocks)
2. **Latent heat storage** – uses phase change materials or PCM store heat by transforming it from a solid state into a liquid state (see Box 6 in Section 7).
3. **Thermochemical storage** - uses chemical reactions to store and release thermal energy e.g. Natural Gas and Biomass. Storage based on chemical reactions have a much higher thermal capacity than sensible heat but (apart from Natural Gas) are not yet widely commercially viable.

UKERC (2014) note that Sensible Heat Storage are currently the most utilised and mature form, with most current thermal storage installations being based on this approach. Latent heat and thermochemical heat storage systems, although potentially provide greater energy storage for a given volume, are still at lower technology readiness levels.

Store volumes range in size from domestic hot water tanks and electric storage radiators designed to store heat (e.g. 300m^3 of heat in a hot water tank) for a few hours, to systems (e.g. pit stores) with volumes of up to 75,000 m^3 used for inter-seasonal storage. However, thermal storage in some forms e.g. hot water tanks or electric storage heaters can be termed as 'invisible' storage, with their capability and potential not fully realised within the UK energy system. With the 'seasonality challenge' that heat demand presents (see figure x below), there are major opportunities for the role of thermal storage in future.

4.1.5 Variability and seasonality of heat demand

Figure 7 from DECC (2012) presents how heat demand (space heating) consists of large seasonal variations, with a fluctuating annual heat load profile, and with peak winter heat load being several times that of the average heat load.

This seasonality is currently served well and relatively cheaply by natural gas (with associated storage / security of supply levels of ~9 days). However, with some energy scenarios phasing out the use of natural gas within the UK to 2050; alternative heating sources and technologies will be of increasing importance.

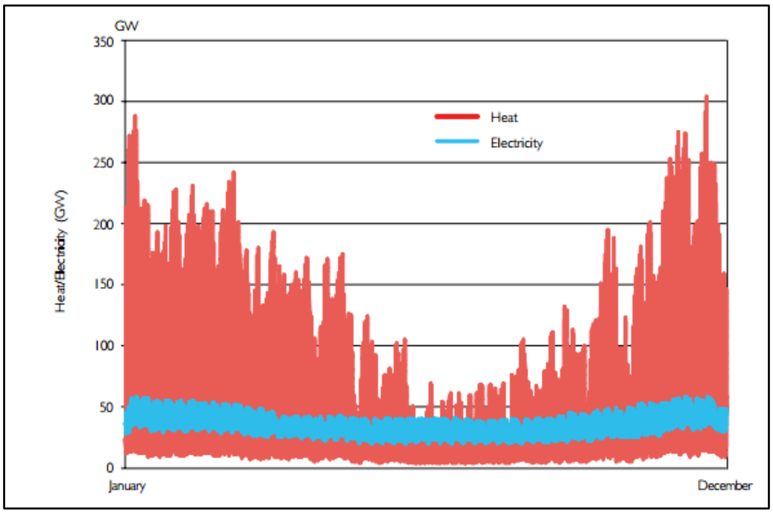


Figure 7: Seasonal variability of heat compared to electricity (DECC 2012)

This means that new or alternative solutions, or adaptations to existing solutions (e.g. natural gas+CCS or a natural gas/hydrogen grid blend) must be able to offer similar value (both monetary and societal) and storage capabilities.

4.1.6 Hydrogen Storage

Deployment of Hydrogen (and related storage) within vehicles, power to natural gas, or underground storage systems is still in relatively early stages. Hydrogen can be stored physically as a natural gas or a liquid and additionally on the surfaces of 'host' solids (by adsorption) or within solids (by absorption). Hydrogen storage can be split into the following main categories with multiple technological solutions within these:

- **Stationary Hydrogen Storage** in the forms of compressed hydrogen (CGH2) in a hydrogen tank, Liquid hydrogen in a (LH2) cryogenic hydrogen tank or 'slush' hydrogen (a mix of liquid hydrogen and solid) in a cryogenic hydrogen tank. These can be stored in i) Underground Storage or ii) inherently within the system in Power to Gas.
- **Hydrogen Storage in Transport** includes a wide variety of storage forms, from compressed and liquid hydrogen, chemical storage, metal hydrides, to a range of physical storage solutions, nanotubes and glass microsphere storage.

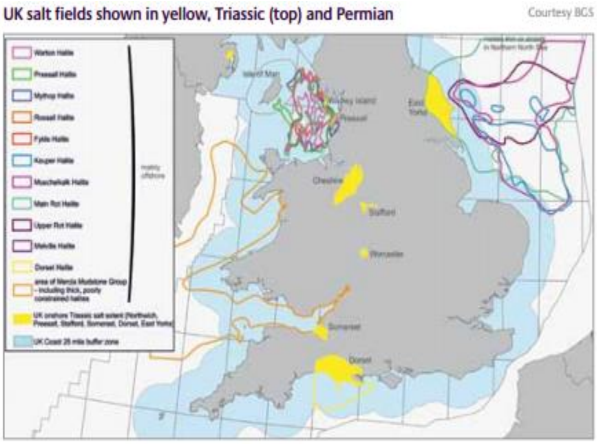


Figure 8: Existing UK Salt Caverns; ETI (2015)

In relation to underground storage (salt caverns), the ETI have recently provided an assessment of the suitability of existing caverns, (traditionally used for natural gas), stating that the use of salt caverns to store hydrogen has the potential to deliver clean, grid-scale load-following energy supplies. Figure 8 below maps these salt cavern sites within the UK, although it is important to note the potential competition for these sites in future if natural gas continues to play a role alongside hydrogen and/or other options such as Compressed Air Energy Storage (CAES).

In regards to Hydrogen in Transport - in June 2016, ITM Power unveiled the first of three hydrogen refuelling stations as part of the Hydrogen Mobility Europe 2 (H2ME2) programme. Hydrogen in transport is therefore in the earlier stages of deployment but could, as a range of scenarios suggest, be a key part of the UK vehicle fleet towards 2030.

4.1.7 Storage in Transport

Adaptations to vehicle types represent major opportunities for changes in energy storage in transport, some of which can facilitate decarbonisation within the UK transport sector. The main decarbonisation routes currently available for transport are Electric Vehicles (EVs), Biofuels and Hydrogen Fuel-Cell Vehicles (FCVs), with Plug-in Hybrid Vehicles (PHEVs) and Liquid Petroleum Gas (LPGs) vehicles as a partial solution. Existing levels of storage in transport can be assessed by considering the current transport mix within the UK including cars, trains, HGVs, marine vessels and aviation.

One example assessment of storage in transport is associated with Heavy Goods Vehicles (HGVs), which (as of 2014) made up just 1.5% of road users, but accounted for over 20% of road transport GHG emissions, National Grid (2014).

The current UK HGV market is dominated by diesel engines, with a very low penetration of Natural Gas Vehicles (NGVs), despite their low carbon benefits. According to the latest worldwide NGV report, the UK has just over 600 NGVs on its roads, with over 30 refuelling stations - National Grid (2014). This shows the market is still in its infancy compared to countries in other world regions such as Asia or the Middle East (Iran has 3.5 million NGVs, 25% of its vehicle mix).

The uptake of NGVs (either Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG) vehicles - both of which use methane-based natural gases), can affect the future types and levels of storage required, for example due to different energy storage densities and fuel availabilities.

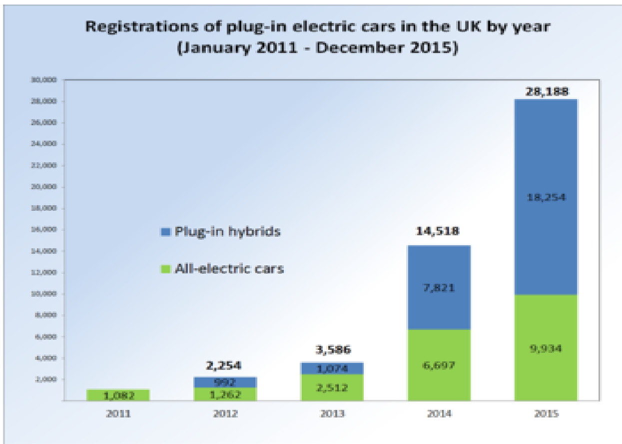


Figure 9: graph extracted from the Society of Motor Manufacturers and Traders (SMMT) 2011 - 2015

Another key example of storage in transport is the increased uptake of Electric Vehicles (EVs) and Plug-In Hybrid Electric Vehicles (PHEVs) as shown in the graph in figure x for 2011-2015. In 2014, a total of 14,518 plug-in electric cars were registered: 6,697 EVs and 7,821 PHEVs, up from 3,586 PHEVs in 2013. 2,476,435 new cars were registered in total in 2014.

This presents both challenges and potential solutions for the grid in dealing with transport electrification. One particular EV-related solution is discussed in Box 8 in Section 7 **[NB: Evalu8 example still to be added].**

5 The value of system-wide energy storage: applications, markets & business cases

Section 5 is still to be fully completed but aims to provide an overview of the applications of storage (and therefore the proposed value it can bring), including in regards externality/societal benefits. The existing and potential UK market for storage will be assessed and relevant analyses of business cases put forward.

The National Infrastructure Commission Smart Power Report (2016), which stated that: *"The UK is uniquely placed to lead the world in a Smart Power Revolution and could save consumers up to £8bn a year".* The Carbon Trust et al (2016), outlined significant cost savings for the UK electricity system, if the potential for electrical energy storage is realised. From their analysis, savings of up to £50 a year on an average consumer energy bill through a system wide saving of up to £2.4bn a year by 2030 have been quoted.

Figure 10 (Strabac et al (2016)) presents the effective deployment volume of electrical storage for different capital cost levels, expressed in terms of £/kW of storage. Three curves are shown, related to economic deployment levels in 2015, 2030 and 2050. The inset table shows the value of whole-system benefits for a cost of £1000/kW. The value of this type of storage increases significantly in the future - for example, assuming the cost of 1000£/kW it would be economic to have 2GW in 2015; 15 GW in 2030 and 25GW in 2050. The net benefits of energy storage increase from £0.5bn/year in 2015, over £3.5bn/year in 2030 to finally reaching £15bn/year in 2050. This suggests that the system will be facing an increasing need for storage - even

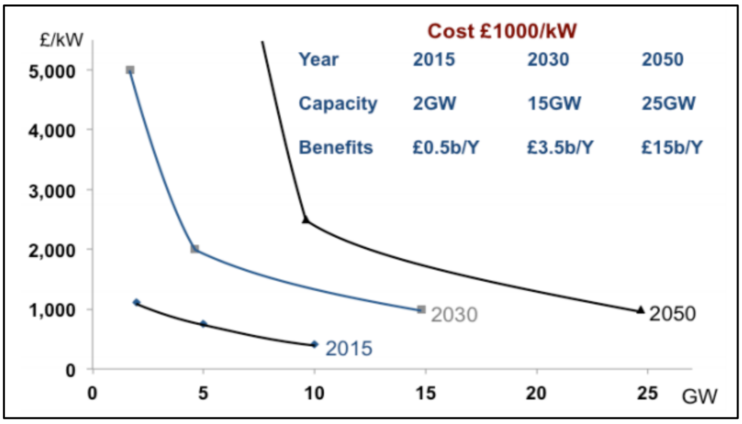


Figure 10: Optimal storage deployment levels for storage (x-axis) for different storage capital cost scenarios (y-axis) in the years 2015, 2030 and 2050 Source: Strbac et al (2016)

if the cost of storage is doubled, i.e. to £2,000/kW, it would be efficient to install 5GW in 2030 and about 13GW in 2050.

As noted however, energy storage is a system-wide service that provides a range of services beyond the electricity sector. ERP therefore aims to consider the wider potential / value of storage assets, with further discussion to be included below.

5.1 Energy Storage Applications & Benefits

The UK energy storage market currently has a keen focus on electrical storage, in particular batteries (due to lowering prices) and the services they can provide. This section therefore begins by presenting these services in figure 11 before moving on to note the benefits of a range of other storage options.

The segments of the circles reflect sectors of the UK electricity system where storage can be deployed, with associated services provided within. Externality benefits (wider benefits not currently valued) are shown around the outside. The inner circles identify services that can be provided at the transmission, distribution, behind the customer meter and behind the generator meter levels. These clearly show that the deeper embedded a storage asset is (distribution-connected, or behind-a-meter), the larger the number of commercial opportunities becomes available to it.

Those in grey however, note a potential issue with storage deployment at the customer level, in the form of *customer levy avoidance*, which can be described as a type of tax avoidance. This is discussed in more detail in Section 7: Barriers. Essentially, storage assets in these behind-the-meter locations are able to provide all of the same types of wholesale market-based services as other assets on the distribution and transmission networks, however, by locating behind-the-meter, they become able to access additional commercial opportunities.

Finally, energy arbitrage under the 'Energy Supplier' category is highlighted in orange as being a key service that can provide externality benefits to consumers.

These services could be provided by other storage options, which integrate with other parts of the energy system. This includes: **[to be expanded]**.

Note to Members - other areas to be discussed / included in this section are:

- Benefits of other storage types – thermal, gas, h2, transport
- Storage cannibalisation – what value can storage provide after ancillary services? Need the storage community to think longer term.
- Combination of business cases (stacking) required?
- Bundling of various storage options e.g. Electrical and Thermal
- More on the UK market for storage
- User driven opportunities and other opportunities

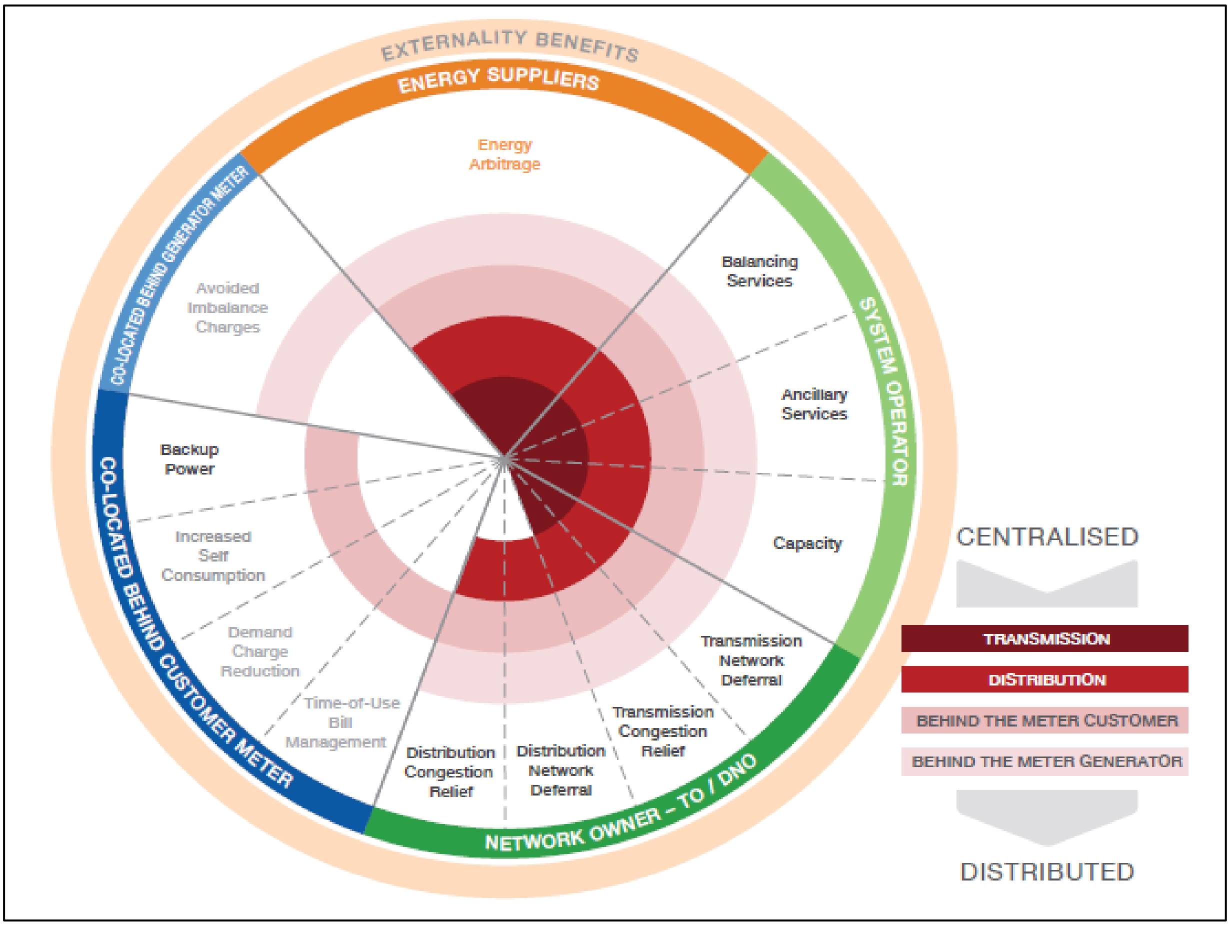


Figure 11: Services from electrical energy storage (ERP 2016)

6 Alternative Options

Energy storage is not a panacea, other options, such as DSR, Interconnection, Networks / Active Network Management (ANM), additional flexible capacity, or alternative vectors such as Hydrogen could provide similar services and Table 1 has begun to try and compare these.

Currently there is no way to value the system services that alternatives could provide, making direct comparisons difficult. Some studies discuss the merits and drawbacks of each of these options but few are able to make direct comparisons of value to the system on a cost basis. Strbac 2016 provides scenario analyses of the options that compete against storage versus those that are potentially more complimentary.

As stated however, there is currently no way to value the above system services, making direct comparisons difficult. This has similarities to a key message raised in ERP's 'Managing Flexibility' report. Levelised Cost of Electricity (LCOE) was cited as being an outdated way to value and make comparisons between energy technologies. This suggests two options, which would help value aspects such as system flexibility, security and resilience: 1) There is a requirement for an updated or additional LCOE type assessment (i.e. an LCOS – Levelised Cost of Storage) to reflect the services that storage provides that aren't currently valued; or 2) as the ERP Flexibility paper suggests - provide a new method of comparing whole system services that aren't purely related to energy, which would incorporate (help value) other options.

6.1 Demand Side Response (DSR)

Demand side response can be used as an alternative to storage and could provide significant amounts of flexibility to the system, with avoided investment in the capital equipment costs that some more novel forms of storage require. However, associated costs need to be balanced against the costs of deploying the control equipment e.g. smart meters with decisions regarding who should pay for these. It is thought that large scale industrial DSR is potentially easier to implement on a £/kW basis, but at a domestic level there can be cost and deployment barriers.

DSR financially incentivises customers to lower, increase or shift their electricity use in real time via a range of incentives as outlined in figure 12. The service can help manage loads (and voltage profiles) on the electricity network but can also enhance usage of thermal storage e.g. via controlled/incentivised use of hot water tanks[3]. DSR therefore essentially utilises intrinsic forms of storage in a more intelligent, controlled way.

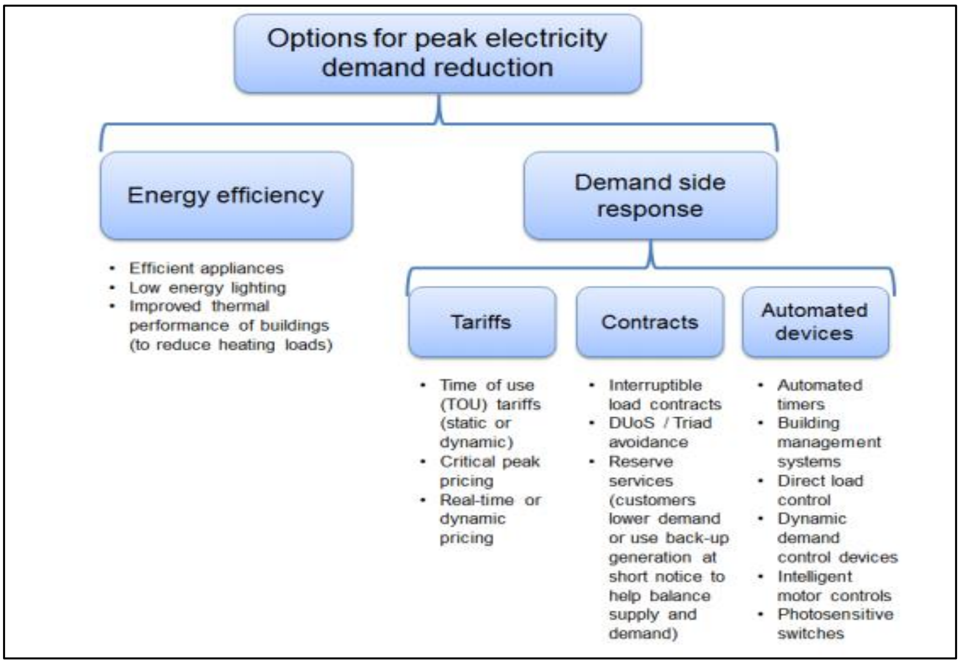


Figure 12: DSR incentive options

Future loads, for example from Electric Vehicle (EV) charging or Heat Pumps can also offer a great deal of flexibility; although the potential of DSR in this case will obviously depend on the availability or uptake of specific assets or technologies.

The table in figure 13 (page 16) presents types of DSR measures (i.e. ways in which DSR can access revenue streams) and the suitable sub-loads to achieve these. It is noted that hot water tanks feature as a capability in every category.

Many of these revenue streams duplicate (I.e. compete) with those accessed by storage. Additionally, as with storage, DSR provides the benefit of reducing the potential need for peaking plant and network reinforcement.

[3] The removal of hot water tanks (which can be controlled via DSR) from within domestic properties could inhibit levels of DSR as an unintended consequence.

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	Option / Solution															
	Electrical						Thermal			Vectors		Transport	Electrical Energy Storage Alternatives			
System Challenge	SMES	Flywheel	Solid State Batteries (e.g. LI-ion)	Flow Batteries (e.g. Redox)	CAES	Pumped Hydro	Sensible	Latent	Thermo-chemical	Gas	H2	EVs / PHEVs	IC	DSR	Networks / ANM	Added Flex Gen
Grid (ancillary) services																
Wind (Renewables) variability																
UK daily peaking																
Smart Grid support																
Energy Efficiency																
End user needs																
UK seasonal heating																
Community seasonal space heat																
Distribution Network																
System Security																
Avoided reliance on Imports																
Fuel poverty																
Decarbonisation																With CCS
Centralised System Control																
Whole System Benefit																

Table 1: System challenges and Energy Storage options and solution

IC = Interconnection

H2 = Hydrogen

Figure 13: DSR Measures & Characteristics

Type of DSR measure	Response time	Duration	Suitable sub-loads[39]
Direct load control	Minimal	Variable	HVAC, refrigeration, hot water
DUoS charge avoidance	Fixed	3 hours	Hot water, lighting, HVAC
Frequency response	2 seconds	30 minutes	Refrigeration (fridges), HVAC, lighting, hot water
Time of use tariffs, CPP, real-time pricing	Variable (known for static TOU, not for dynamic tariffs, day ahead for CPP)	3 hours	Hot water, lighting, HVAC, refrigeration (freezers / cold storage)
STOR	Up to 4 hours[40]	2 hours	Hot water, freezers, lighting, HVAC (and back-up generation)
Triad avoidance	Day ahead	2 hours	Hot water, refrigeration, lighting, HVAC

Among those interviewed, Time of Use (ToU) Tarriffs have been cited as an important and useful DSR tool to help manage peak demand, save network investment and other costs associated with managing flexibility in future. However although DSR can utilise existing assets, costs associated with increased digital infrastructure need to be taken into account.

A report written by De Montfort University for Ofgem (2012) highlights the issue that estimating the technical potential for DSR is inherently uncertain. For example, the extent to which heating demands in a particular building may be delayed depends on a number of factors and estimating those who will partake in DSR arrangements is difficult. Assessing the potential for DSR at the national level is therefore a challenging task. This view is supported by the ranges quoted for the potential of DSR which are in the region of **5 and 20GW of potential capacity** - although it is noted that the higher stated figure is subject to "extreme uncertainty", and is largely based on *technical* capability as opposed to *realistic* capability which requires further assessment.

Although still in its infancy, DSR is increasingly seen as an important and valuable tool. National Grid's *Power Responsive* campaign is underway to provide a practical platform that galvanises businesses, suppliers, policy makers and others to seize the opportunity to shape the growth of demand side response collaboratively, and deliver it in practice at scale by 2020. DSR is therefore thought to have potential alongside (if not sooner than) the deployment of many electrical storage technologies.

Finally, the barriers to DSR have also been investigated by De Montfort University (2012), with some of these (particularly in relation to the non-domestic sector) included in figure 14 below.

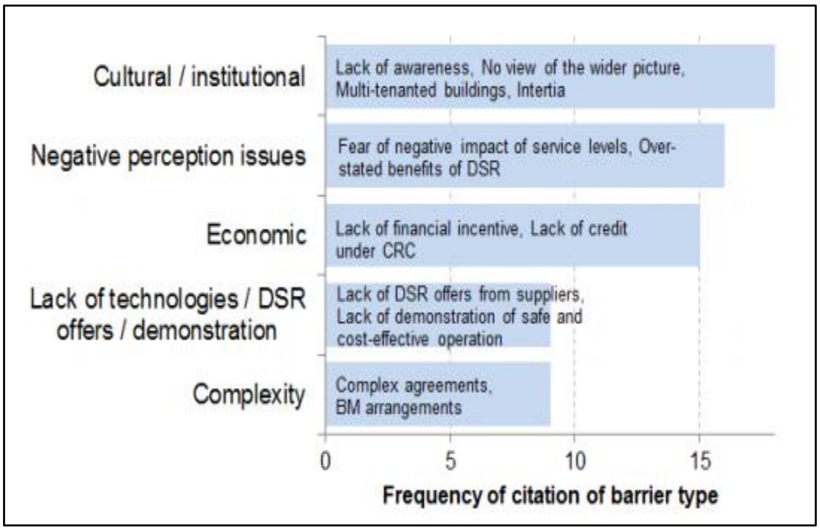

Figure 14: Barriers to DSR – as noted by the non-domestic sector

6.1.1 Aggregators

Aggregators such as Tempus Energy and Flexitricity currently help facilitate the integration of DSR. These businesses make predictions of imbalances between demand and generation (i.e. for each half hourly settlement period), assess levels of flexibility available (consumers that are able to reduce, increase or shift energy use at a given time) and with pre-arranged agreements, can control aggregated energy supplies to assist the System Operator, helping control imbalances and peaks. There is the potential for DNOs to provide this function in future and this is something that could be considered further.

6.2 Interconnection

Great Britain currently has **4 GW of interconnection capacity** (equivalent to 5% of total generation capacity) via four interconnectors - two linked with Ireland, one with France and one with the

Netherlands. The existing ‘cap and floor’ regulatory regime has successfully begun to increase interconnection schemes that can deliver significant benefits to UK consumers e.g. as an overflow system that can avoid expensive ‘flexing’ of existing plant. By the early 2020s, **~11.3 GW of capacity** is expected, with new connections to France, Norway, Denmark, Ireland and Belgium, and potential for others.

However, the role interconnectors can play is likely to change over time and is determined by factors such as the UK’s future generation mix, political relations with interconnected markets that can place security of supply at risk, localised weather patterns and available surplus at the other end – all these factors could inhibit the full benefits. A key benefit (in both directions), if this latter concern is not applicable, is the ability to export low carbon energy at times of surplus, or flexible generation to support that variable energy, as needed.

A 2012 report from Climate Exchange reviews analysis carried out by AEA (2010) and suggests that in the nearer term, interconnection is a more cost-effective option. However, longer-term solutions are required and should be sought and actioned upon now to improve future situations.

6.3 Networks & Active Network Management

TBA

6.4 Added Flexible Generation

TBA

6.5 Comparisons

Table x below **(still to be completed)** presents a range of advantages and disadvantages associated with the above potential solutions. Electrical storage is used as a direct comparison here, before alternative options to other forms of storage e.g. hydrogen in place of gas, are discussed below.

Energy storage provides a range of advantages, although its value is currently considered longer term (figure 15). However, in order to create and capture that longer term value, storage solutions must be able to compete with other solutions on a level-playing field and start be deployed now.

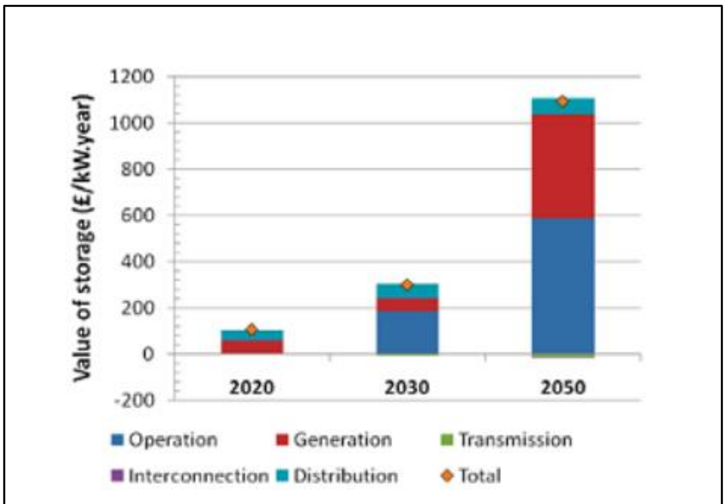

Figure 15: value of storage in 2020, 2030 & 2050 Source: Imperial College (2012)

A key advantage of storage is that it can be dedicated solely to providing flexibility services. Another is that (as discussed previously), large levels of storage and associated infrastructure already exist. It is more novel forms of storage that are currently higher cost in comparison, although these options can create notable benefits too.

At present (apart from pumped hydro which is already in widespread use), relative to alternatives (like network reinforcement, active network management, and emerging solutions like demand side response or the use of solar and wind power for network balancing); the costs of novel energy storage technologies appear high and their usefulness is constrained by factors such as the hours of discharge they can provide daily, reliability, energy conversion efficiencies and operating lives (Scottish Enterprise, 2016). The value of electrical energy storage (and to an extent thermal energy storage), is currently largely dependent on levels of renewables.

DSR is thought to provide increased solutions in the shorter-term (to 2020) with network cost reductions and savings from reduced peaks; however the service utilises assets that are also used in other ways and is therefore reliant on (to provide examples) hot water tanks being available to switch off, or vehicles not being used at specific times of day to enable Vehicle to Grid (V2G) capability. The range of estimates in terms of DSR potential varies greatly and requires further analyses, although to some extent, it will only be as uptake of DSR capabilities increase that the full extent of its potential can be assessed. DSR could be considered *as* a *complimentary solution* to storage, as it effectively makes efficient and controlled use of inherent storage assets across the system.

Interconnection can also provide a shorter term solution and currently has a successful incentive to increase deployment with the 'cap and floor' scheme. However, increased reliance enhances security of supply concerns and neighbouring countries with similar weather patterns could force interconnector assets to act like storage with significantly lower availability than a physical storage asset (ERP 2015).

The graph in figure 16 is taken from an Imperial College (2012) study for The Carbon Trust and highlights the effects of increased use of other solutions on storage. Unsurprisingly, interconnection, flexible generation and flexible demand (demand side management) all significantly reduce the value of storage.

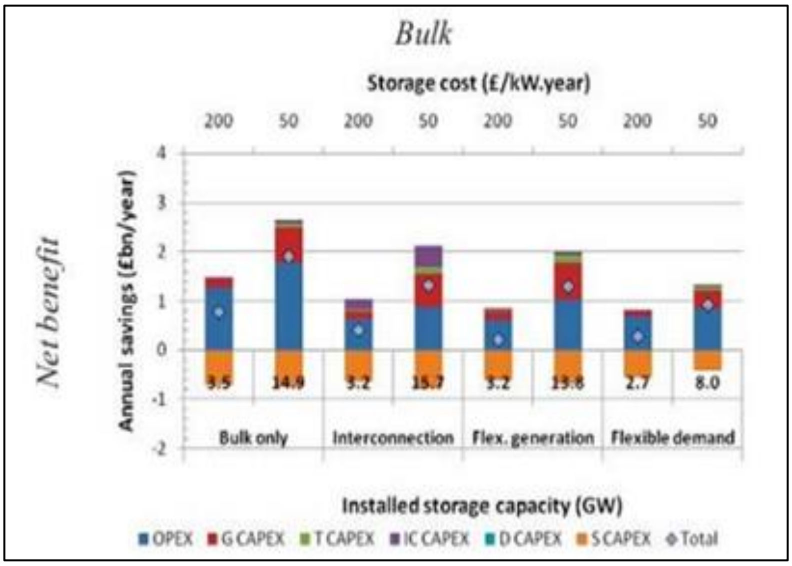

Figure 16: the effects of IC, Flex Gen and DSR on electrical storage; Source: Imperial College (2012)

Within this analysis (even at low penetrations of 10%), DSR tends to have the highest value compared with other balancing technologies. The work does however, assume no costs associated with DSR. Although smart meter roll-outs are already taking place, there are likely to be further technology and non-technology costs associated with this measure e.g. further smart meter/data/comms equipment, system upgrades for suppliers, product changes or compensation for consumers, or incentives / rewards for specific behaviours. This may therefore overestimate the value of DSR, particularly in comparison with storage.

Electrical Storage Potential: 5GW		DSR Potential: 5-20GW		Interconnection Potential: 4-11GW		Networks / ANM Potential:		Added Flex Gen Potential:	
✔	✕	✔	✕	✔	✕	✔	✕	✔	✕

Table 2: Comparisons of the advantages and disadvantages of electrical storage and alternative solutions 2020-2030

Note to Members - other aspects to be included are: Complete table and other sections for comparison; Hydrogen as an alternative to Natural Gas - *Would reduce the scale of variability on the electricity networks*; Alternatives to heat and transport storage? Other types of storage.

6.6 Other storage options

Given that a barrier noted by some of the finance community related to a lack of information or awareness of the full range of storage applications available to invest in, information of some less well-known storage applications are included below.

Box 2: Energy storage aboard marine vessels

Energy storage has seen significant improvements in terms of energy density over the past decade, transitioning from the likes of rechargeable Lead-Acid, NiCd, NiMH, to Li-Ion with power densities ranging from 30Wh/kg to over 200Wh/kg. It is mainly these advances in battery capabilities that are technology enablers. Ultra-capacitors have also seen advances in recent times and have their place in short-term high power applications, such as heave compensation - although the high cyclical duty can be damaging to batteries which can have typical lifetimes in the order or 12,000 cycles for 80% depth of discharge (DoD), and are also significantly impacted by operation temperature range. However, for a ferry application with good temperature regulation, transitioning ports ~10 times per day, would have 3 years+ lifetime and increased battery lifetime can be achieved by reducing the DoD.

Energy storage can therefore bring significant benefits to the marine domain across numerous differing applications. Using a storage asset, a ferry with a shore connection during boarding can re-charge, disconnect and then 'transit port' under "zero-emissions mode" (a mode which is now being mandated in some ports). It can also benefit from improved operational efficiency, reduced fuel consumption, and improved operational and dynamic performance. As noted, the ferry can transit port in zero-emission mode, and then revert back to traditional propulsion for the crossing; or alternatively under electric propulsion system mode for the remaining duration, depending upon the installed energy store capacity. This is just one of the many applications benefitting from a more electricity-based approach and from the integration of energy storage.

The additional costs of these more electric systems in this scenario are largely supported by improved efficiency gains. Battery evolution is certainly enabling operational benefits on marine platforms, which are 'mini' power stations and grid networks.

The application of energy stores can be categorised into two main areas within this context: one requiring large scale energy storage for sustained use, and the other, smaller scale storage for short duration, high power use, i.e. sustained energy, or power applications respectively. Ferries fall into the initial category whereas Drill-Ships and Platform Supply Vessels (PSV's) fall into the second category due to their relatively short utilisation profiles.

Drill-ships present a different challenge due to the heave compensation requirement, having a high cycle count and large power requirement on their energy storage mediums, but with large potential gains in terms of emissions and efficiency since you can perform load-levelling and potentially reduce the number of generators online supporting the power peaks. In summary, these operational characteristics dictate the energy store required to support the application, the power conversion technology generally being agnostic.

For more information on marine energy storage applications: *Integration, optimisation and benefits of energy storage for marine applications (Radan et al, 2016).*

7 Barriers to System-Wide Solutions

This section discusses in greater detail (with associated examples) the main barriers included in the **key messages section (pages 2-5)**, plus others that have come to light throughout this project process. Those listed and discussed are considered to hinder the potential of whole system energy storage services the most.

Barrier 1: System-wide services and solutions such as energy security, resilience and flexibility are currently undervalued.

Energy storage assets can provide a range of services and solutions that are key to the UK energy system at a strategic level. Storage assets are additionally able to participate (or compete) in a variety of markets which brings a range of potential benefits but conversely, barriers and complexities associated with fragmented business cases too.

Some of these services are considered 'externality benefits', such as avoided investment in transmission and distribution networks for electrical storage or in community heat networks for thermal storage. These benefits are therefore not valued within current market arrangements.

As noted in Section 5, there are a range of services, solutions and benefits that society requires **[NB: section 5 still to be completed]**. However the above noted lack of valuation can result in a loss or under-delivery of storage and the associated benefits it can bring. This particularly creates an issue in cases where a specific market need is not being met, although it is acknowledged that in some cases, alternative solutions to storage can provide these.

Identification and clarity from policy-makers regarding the required levels of key system services (i.e. energy security, resilience and flexibility), with associated system 'metrics' and newly created mechanisms, would help secure or stimulate markets in these areas. This would allow storage (and other solutions) to compete on a level-playing field, whilst ensuring these services were valued appropriately at both the system and individual asset, or community, levels.

One example (with a focus on electrical storage) can be drawn from California, USA which has made steps to value flexibility and has effectively allocated segments of its electricity market to storage to provide this. Energy storage procurement targets for each of the Investor Owned Utilities (IOUs) totalling 1,325 MW have been set, to be completed by the end of 2020 and implemented by 2024. Although the UK may wish to open the market wider than storage services only, this example does present how the requirement for flexibility (as one example) and the services that provide it, could be further defined and valued.

The Capacity Market in the UK is one mechanism that enables the ability to pay for a *service* (i.e. energy security). The market places emphasis on *capacity* (MW) with associated payments, as opposed to *energy* (MWh). This can be used as an example of providing a market arrangement associated with a service that incentivises providers to compete.

Finally, despite the key potential role of natural gas in a low carbon future, the benefits and flexibility it provides are not properly recognised or valued within current market arrangements. Natural gas provides a low cost, flexible and reliable form of storage and is a way of managing and mitigating supply chain risks. However, levels of import become an increased risk if supply chain disruption lasts longer than the storage duration provision. The gas market is currently based on a *daily* value with no consideration of the *within day* flexibility that it provides and is therefore deemed to be undervalued.

Barrier 2: The future role of storage and its potential system-wide benefits (in relation to other options) is not yet fully clear.

This report considers energy storage as a system-wide service that is undergoing changes from existing and inherent forms, to more novel forms with a potentially increased or prominent role. This role is not yet fully realised and there is therefore the need for a more strategic, impartial consideration of the benefits that storage can have across the UK's energy sectors.

Improved alignment of activities, plus a clearer whole-system direction (strategic level decisions that guide the market), would help characterise and value system services whilst encouraging storage to compete alongside other alternatives.

It is noted that storage is not the only asset that can facilitate solutions across the three main pillars of the energy sector (see figure 17 below), although it is one option with the capability to compete in a range of markets, which within the right conditions and circumstances, can afford a variety of benefits. A mix of storage solutions are therefore likely to be required and a consideration of these requirements and their benefits at a system level (to include macro *and* micro (i.e. local) level benefits) would help pin-point those required.

Different solutions e.g. energy storage, interconnectors, DSR etc, to some extent provide the same services, but to some extent, provide different services. There is current ambiguity regarding the potential future value of these options however once deployed, these are long-lived assets and part of the energy transition. There is currently no effective market solution for evaluating whether an option should be invested in (linked to key message/barrier 4).

This is where an organisation with the capability and responsibility for designing, advising and facilitating the UK energy system from a whole-system perspective would be valuable and is therefore recommended. This role should be provided by a dedicated independent or government body and should include assessments of services and technologies that provide benefits and solutions across the three key sectors of energy: power, heat and transport. This body would help to define high-level decisions before allowing the market to play its role, which in turn would drive down the cost of capital and increase investor confidence.

The Future Power System Architecture Project (FPSA) project commissioned by DECC[4], is likely to help provide further details of the type of organisation required. It is important that any such body should focus on alignment of services and solutions across the whole energy system however i.e. not focus solely on the power sector.

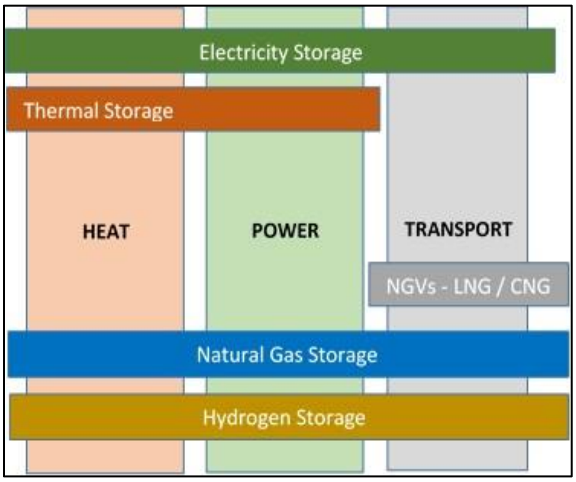

Figure 17: Energy storage is a solution that can provide cross-sector services

Barrier 3: Existing regulatory frameworks do not consistently provide clear signals and opportunities for system-wide storage projects.

Where there *are* clear signals of the need for storage a range of barriers exist that can prevent storage services from progressing or being adopted – these are discussed as part of Barriers 4 & 5 and additionally later on in this section. Notable examples of these are: helping the system manage the variability of renewables, or the electrification of transport; or for assisting with peak heat demand.

Two key options that have come to light for addressing these barriers are:

[4] undertaken via a collaboration between the Institute of Engineering and Technology (IET) and the Energy Systems Catapult (ESC)

i) Provide storage with its own dedicated treatment (e.g. subsidies, tax breaks, a legal definition) and/or its own regulatory framework;
ii) Adapt the existing regulatory framework to promote a level-playing field and remove the disadvantages currently faced (e.g. double-charging for electrical storage).

ERP recommends that the current system should be adapted (option ii), to allow storage to operate (and compete) without being disadvantaged. Cases for dedicated treatment e.g. subsidies have largely being phased out, and are seen as an unfair advantage and/or a short-term fix,

In some circumstances however, the case or requirements for special treatment can be put across to either solve a barrier that currently prevents the full benefits from being realised, or to simply allow a storage asset to begin to compete fairly in a circumstance where it currently can't. Examples of these are discussed in more detail in Section 7.1 but can be cited in relation to:

- 'Double network charging' of electrical storage which is also relates to its legal definition[5];
- Licencing regimes (EU regulations) that state network companies cannot be storage owners *and* operators;
- Current unsustainable business rates that could place natural gas storage assets at risk.

Although issues such as these may seek to be addressed, associated actions should be carried out to ensure that:

- All technologies / service providers can subsequently compete on a level playing field;
- A storage asset can provide the role it has ideally been identified to achieve (via clear system direction with recognition of a system need, and associated regulatory measures that drive market signals);
- Benefits can largely be captured *system-wide* as opposed to purely at the local level (system-wide benefits should in any case incorporate the capture of local benefits).

The above doesn't necessarily mean that storage requires or should receive special treatment, as it is noted that a truly flexible and resilient energy system or market, with a clear direction, should be able to successfully accommodate and incorporate energy storage services that serve key system needs. Achieving this should remove many of the requirements for special treatment.

Additionally, cases for dedicated treatment should to be balanced against i) whether the treatment will result in the ability to compete on a level playing field with others (as above) - in which case this is arguably <u>not</u> special treatment vs ii) whether the treatment will provide an intended, or unintended advantage. This latter option may reflect how 'valuable' (both intrinsically *and/or* economically) a storage service is to society as indicated by signals from research, government policy, regulation and markets, and therefore whether it is chosen to be deployed.

A final point is that providing dedicated treatment may force a case for storage in specific circumstances when there isn't a clear market need, or where other existing options could provide a similar service at a lower cost (e.g. services that existing natural gas or pumped hydro can provide vs more novel forms of storage). Additionally, special treatment could also interfere with barriers that may naturally fall away. An example here is the reducing costs of some storage options that have already occurred (albeit steadily over 20+ years) as uptake has increased, e.g. Lithium Ion batteries, or new thermal technologies such as heat batteries (see Box 6 Phase Change Material (PCM) Thermal Energy Storage below).

ERP recommends a deeper consideration of the *whole-system* need for storage, the value that various storage services or technologies can provide and whether these are currently disadvantaged compared to other options. This will help make decisions regarding whether dedicated treatment required.

[5] Electrical energy storage is currently defined as both generation *and* consumption under EU & UK regulation (as of July 2016)

Barrier 4: There is a shortage of *risk-capital* and a lack of certainty to help fully inform investment decisions regarding i) the opportunity and breadth of storage projects available and ii) the risks of investing.

There is no shortage of available capital and a keenness to invest in energy system projects and assets (including storage) if the risks are well understood and manageable. However, aspects such as the value of services that storage provides, volatility of associated revenues and the potential mismatch of duration risk (i.e. the forward visibility of contracted revenues being less than the timescale of returns for asset finance), currently hinder many projects from being financed. Successfully unlocking the initial levels of investment will help facilitate investment and unlock larger amounts of capital.

Additionally (and linked to key message/barrier 1), energy storage is currently under-valued, in part due to investment costs (which are high) vs payback periods and/or contract lengths, but also because there are missing markets for valuing the services it provides.

Some storage assets are currently viewed as riskier to invest in and therefore have to be financed solely by equity (at a cost of 20+%). Large pension funds are keen to inject capital but require predictable returns which results in a shortage of *risk* capital. Improvements of regulatory systems can help address this debt vs equity allocation mismatch and ensure that the lowest cost of capital is included within the transformation of the system. It has also been noted by the finance community that there needs to be a shift away from financing *assets* only, to additionally financing the *services* that energy storage can provide.

Placing a value against providing services such as flexibility, system security and resilience in a technology-neutral way (as recommended above) would help reduce risk and provide an idea of the various market sizes for storage. This would also allow other options that can provide these services to compete and newer options to come forward. However, following on from placing a value on these services, a subsequent question is how to pay for the value of a service? One view put forward is that some of the risks that a storage asset is exposed to are similar to interconnectors in terms of arbitrage spread. Mechanisms similar to the 'cap and floor' for interconnectors, CfDs or long-term contracts are all potential options what would help provide a form of insurance for investors.

Barrier 5: A key commercial risk applies particularly when considering storage as an additional or retrofit service to be added to sites with pre-existing infrastructure and commercial arrangements.

There is currently a commercial risk relating to storage, mainly when considering it as a bolt-on or retrofit service to be added to existing sites with existing infrastructure and commercial arrangements. In these cases, adding storage to the mix can often place at risk, or invalidate these pre-existing arrangements. Therefore even if (i) the overall economics will be improved, (ii) there are strong environmental and social rationales, and (iii) there is interest from investors and generators - there is a reluctance to incorporate storage because this can add risk to core arrangements in place.

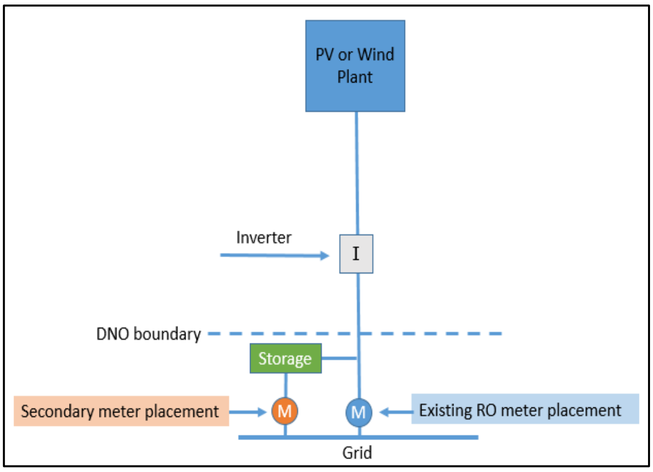

Figure 18: Wind/PV site scenario

Examples include risk to returns gained on existing assets via offtake agreements, and loss of ROC or RHI payments. The example in **Box 3 and figure 18: Regulatory Barrier example Electrical Energy Storage: Wind & Solar** explains more.

Box 3: Regulatory & Commercial Barrier (Barrier 5) - Electrical Energy Storage: Wind & Solar Retrofit

This text provides an overview of key barriers cited by Wind/PV developers interested in adding electrical storage to existing sites.

Outline of scenario and issues:

- Grid connection paid for at Wind/PV planning stage
- Investment agreed based on i) power produced (Power Purchase Agreement - PPA) and ii) calculated ROCs
- Overall capacity of Wind / PV site ends up being less than required (for example due to the removal of turbines during planning consent process), therefore spare capacity exists to incorporate storage.
- Current codes require meter placement (blue box and blue 'M') at the network boundary. This meter determines the ROCs the site receives to ensure it has come from a low carbon source and is eligible.
- Integrating storage into existing site infrastructure typically requires the storage asset to be situated 'behind-the-meter' i.e. the blue 'M', since it can be technically difficult to connect the storage between the export meter and the Grid. *[NB: This is more driven by practical considerations as opposed to best location for smooth the variable output]*
- Using a different technology profile within any un-utilised capacity is routinely treated as a complete material change to the grid capacity originally planned for the site, hence applications for modifications are treated by DNOs as new applications for the change of technology.
- Grid connections are issued on a first-come, first-served basis and result in lengthy waiting times.
- Consideration of the addition of storage by the regulator will temporarily halt ROC payments which results in loss of revenue, increased risk and an interrupted PPA / offtake agreement. It is also not possible to obtain full confidence that any proposed site amendments will be re-accredited, leaving investors of existing sites fully exposed.

Potential Solutions:

- Reassess the RO rules, in particular the way ROCs are reconsidered when changes to these situations occur. This option is most likely to be infeasible due to the length of time this would take. However, **'pre-approved' configurations or operating models for retrofit storage could give comfort to investors that a scheme would get re-accredited**, provided it was built and integrated in a way that avoided 'gaming' the RO meter. For example amendments to move the RO meter to just after the inverter, would allow storage to feed-in after this meter and hence leave the RO payments unaffected.
- **'Fast-track' connection times for sites with pre-existing, pre-paid grid connection** with spare capacity, whilst ensuring the perception of 'special treatment' is avoided
- **Allow a secondary meter placement for storage (Orange box & 'M'),** although there are potential concerns over a 'secondary ROC market' with this proposed solution.

It is felt among the renewables community that if these barriers were to be fully considered and solved, then the market for storage in these scenarios would be able to compete fairly.

7.1 Other Key Barriers

A number of additional barriers to system-wide energy storage have been uncovered throughout this project process with a selection of these noted below. Many relate to electrical storage given the current market interest, however additional barriers included relate to a wider range of storage options and assets.

Network costs: 'Double Charging' of electrical storage

This is a well-cited barrier that relates to the need for non-traditional business models and changes to outdated regulation or charging models that can no longer incorporate more novel forms of storage. Storage is currently charged network costs that are associated with generation *and* consumption. Energy that is being imported from the grid (during the charging phase) is subject to one set of grid charges, whilst energy exported to the grid (during the discharge phase) is subject to another set of grid charges. This 'double charging' does not appropriately reflect the value of storage to the system and can hamper deployment.

However, this barrier does depend to an extent on what purpose the storage is used for. As long as these double charges are cost reflective of the situation and use, then double charging is deemed not to be an issue. For example, if a storage asset is used in an arbitraged mode for personal profit at the distribution level (charging at times when energy prices are cheaper and discharging at times when prices are higher), then these charges are deemed to be cost reflective of the networks being used. If however storage is being used for grid services, to support the system, then this double-charging removes the incentive for doing so (creates a barrier) and is not considered cost-reflective.

The legal definition of electrical storage

The above charging issue is linked to the way in which storage is currently defined within GB and EU regulation. Unfortunately, any change in regulation will not be a 'quick-win' and will take time to address. However, in addressing this issue, it would be helpful to outline the particular circumstances or situations when storage is deemed to be (and therefore should be charged as) generation and/or consumption. This would help to provide clarity for storage developers and their business cases.

Ownership of electrical storage – Distribution Network Operators (DNOs)

The EU Third Package, was designed to separate supply, generation and network operations and to break up big vertically integrated companies. This package currently prevents DNOs from controlling generation or supply activities which presents a barrier due to the fact that storage (in addition to consumption) is also classed as generation under the directive.

This means that DNOs are not able to control supply or the sale of electricity to wholesale or end-use customers which presents a barrier to the fully beneficial control and use of storage at the distribution level. Although Ofgem are aware of this issue and have been working to assess how to address this[6], as noted above, there is little scope to change this in the short term.

Market price distortions: Customer-level deployment of electrical storage (at scale) and associated tax avoidance

This barrier relates to the diagram in Figure 11, in Section 5 and supporting text, regarding a potential issue with storage deployment at the customer level. This issue is in the form of *customer levy avoidance* which can be described as a type of tax avoidance. Essentially, storage assets in these behind-the-meter locations are able to provide the same types of wholesale market-based services as other assets on the distribution and transmission networks. However by locating behind-another-meter, they become able to access additional commercial opportunities.

These additional financial benefits to the customer arise from reduced use of energy which is usually produced some distance away and transported via the distribution or transmission systems. This energy is replaced with greater on-site usage of behind-the-meter, self-generated energy which could be from carbon emitting, or (low carbon) renewable sources.

The additional benefits of storage to the customer only arise from opportunities to arbitrage[7] against retail tariffs (as opposed to wholesale tariffs) and can be over and above the market revenues available to other storage connected to the grid. This retail price arbitrage opportunity arises because particular charges are only levied on consumption served by remotely generated electricity, and are not levied on consumption served by generation that is behind a demand meter. The retail price of power is much higher than the wholesale price of power partly because the retail price includes a range of

[6] Ofgem have looked at high-level models for DNO operation of storage with different business models and commercial arrangements possible for each

[7] charging at times when energy prices are cheaper and discharging at times when prices are higher

additional consumption-based levies charged on retail customer demand, which, through greater "self-sufficiency", the customer is able to avoid.

The purpose of these levies is to collect revenue to pay for government policy costs including: Renewables Obligation (RO), Feed in Tariff (FiT), Contracts for difference (CfD), Energy Company Obligation (ECO) and Warm Home Discount (WHD). The method by which network and system balancing costs are charged also add considerably to the retail:wholesale arbitrage that encourages "energy self-sufficiency".

This use of behind the meter storage for the purpose of customer levy and network cost avoidance therefore creates a challenge for society because the total cost of these needs still needs to be collected but results in higher unit rate charges for all other customers. An additional recommendation is therefore that policy and regulatory parties should assess whether and to what extent these incentives and resulting actions represent distortions compared with accurate market price signals.

Incentivising delivery of the 'energy trilemma' via regulation and contract lengths

Regulatory systems do not fully incentivise solutions that deliver on the long-term energy trilemma. Long-term Power Purchase Agreements (PPA) or offtake contracts that support the lower cost of capital should deliver on the lowest cost of energy *together* with decarbonisation, as these contracts will drive down the lower cost of capital. Assets that age but currently provide capacity, such as diesel gen sets, should arguably be on very short term contracts because they don't tick all three boxes of the energy trilemma, other assets that do should be provided with investor certainty via longer-term contracts.

Energy costs disproportionately borne by the costs of *electricity*

It has been noted that energy costs are currently disproportionately borne by the costs of *electricity*. Government attempts to reduce the carbon intensity of energy are therefore borne by those who use electricity rather than other/all forms of energy. This makes energy storage options across all sectors more expensive and should perhaps be reconsidered.

Low revenues & high costs – natural gas storage

Natural gas storage in the UK is valued and contracted for on the basis of the intrinsic and extrinsic value perceived by the commodity market on a forward basis, a value which is lower than the real value delivered to customers every day.

The intrinsic value of natural gas storage reflects the seasonal spread and is the value of storing relatively low priced summer natural gas and selling it during the higher priced winter months. The extrinsic value reflects the optionality of capturing short term price volatility and is related to the number of cycles that a storage facility can perform.

Over recent years, both intrinsic and extrinsic value has reduced, creating a negative impact for storage owners. Seasonal spreads have declined by 75% since 2010, in part due to reduced seasonality of demand and the availability of LNG; and the value of natural gas storage has fallen well below operating costs. Additionally, the industry feels that business rates are a cost burden that, combined with reductions in revenues due to deterioration in price spreads (as above) and market volatility, could place natural gas storage assets at risk.

Based on discussions with natural gas storage operators, business rates currently often represent between 25%-35% of costs. This combined with income levels under the current market, means that natural gas storage income is less than the costs incurred to operate. For some storage owners with lower income, as much as 50%+ of this income goes towards paying business rates. If natural gas is to continue playing a significant role in providing system flexibility and resilience to towards 2030 and beyond, then these unsustainable levels of cost need to be addressed (see Box 4).

Box 4: Removing the barriers to the future of Natural Gas Storage - EUA Utility Networks Report (2016)

The benefits provided by natural gas storage to the network are not properly recognised or recompensed under current network arrangements. The need for investment by the pipeline operators in the natural gas network is reduced by the fact that storage is embedded in the network, close to customers, and can be relied upon to deliver natural gas during times of need.

If natural gas storage was not on the system, not only would UK need to secure additional imports, the network operators would also need to invest in costly system reinforcement to allow the system to deliver that natural gas to customers. The costs of this reinforcement would ultimately be borne by customers through higher natural gas bills.

To correct this anomaly, network tariffs incurred by users of natural gas storage should be reviewed and reset to better reflect the network investment savings created by storage flows.

This could be achieved by placing an obligation on National Grid, in its role of Gas System Operator, to acquire within-day flexibility services rather than investing in less economically viable network infrastructure projects. I.e. buy services from gas storage facilities when demand is high and pressure in the pipeline drops. Gas storage could inject into the NTS to keep the pressure up (rather than the SO having to act). This could also work in the reverse situation when demand is low and pressure is high - gas could be taken off the NTS to reduce the pressure.

Other notes regarding barriers uncovered so far [NB all barriers will eventually be sorted and presented in tables relating to financial, political, regulatory, legal, commercial barrier categories]:

- Transmission & Distribution charges don't currently encourage a level playing field and provide the right signals to value electrical storage at the right locations.
- As end users increasingly choose to go off-grid, there is the risk of a further fragmented energy sector which will make the aggregation of policy solutions harder.
- Devolved administrations need to be enabled further to devise their own local solutions. These administrations could have responsibility for the deployment of energy storage as part of devolution agreements.

Thermal Storage:

- Heat could be more widely used as a form of storage from electrical generation, similar to the concept of a CHP system. Dual electricity-heat benefits would incentive take-up.
- Large amounts of heat storage is currently being lost or removed from the system. There is no real incentive to retain certain forms of heat storage (e.g. hot water tanks) within homes and policy has played a part here.

Hydrogen:

- Hydrogen can provide storage in the same way as fuels. It can also provide similar services to the electricity grid similar to other options, such as batteries and pumped storage.
- A key benefit of hydrogen is that it can serve multiple markets, e.g. power-to-gas, transport and heat, and therefore does not have to be converted back to electricity. However this requires a cross-sector approach to the energy system to fully assess the value hydrogen can bring.
- In addition to other key benefits e.g. storability, transportability, mobility and suitability for larger vehicles, along with the potential to use it for heat (instead of electrification), Hydrogen will start to look more attractive when considering a valuation for resilience.
- Despite the attractiveness of Hydrogen, the finance sector are somewhat cautious regarding investment because it is not yet clear whether there will be a global market, or what the

related prices for provision will be. This was particularly noted in relation to transport, where an international market for pure EVs is developing, with uncertainty about the development of Fuel-Cell EVs. This view was challenged, in relation to there being clear benefits of Hydrogen for assisting with the seasonality of heat.

Transport:

- Storage from transport (EVs) can provide a useful solution to assist with grid balancing but requires planning as part of system-wide solutions.
- There are opportunities to re-use or ‘second-life’ older batteries from EVs to assist the grid with charging requirements. These can be used as localised storage to mitigate the challenge of reinforcing local networks in order to manage a local peak load caused by multiple vehicles attempting to recharge at the same place and same time.
- The risks and trade-offs of building national infrastructure for EV charging need to be considered in terms of other solutions e.g. market entry of hydrogen/fuel cell vehicles.
- Transport currently already provides a certain level of storage in fuel tanks and within transport energy infrastructure itself.

[NB: Example box to be added with information regarding Evalu8 – provision of V2G services and re-use or second-life-ing of redundant batteries to assist the grid with charging requirements]

Box 5: Political Barrier example - Thermal Energy Storage: Domestic Hot Water Tanks

An unintended consequence (in energy storage terms) has arisen from legislation produced between 2005-2007 in England and Wales - with similar regulations in Scotland and Northern Ireland - that all new natural gas central heating boilers and oil-fired boilers are to be replaced with higher efficiency condensing boilers, with improved efficiencies of up to 10-12%. DECC 2014 state that the share of the market for combination (or ‘combi’) boilers has approached two-thirds of all boilers in the UK, with *condensing* combi boilers making up a third of all natural gas and oil boilers.

These boilers are not only attractive for their increased efficiency and cost (natural gas is generally about ¼ of the price of electricity) but as a more modern facility with reduced spatial footprint. However, these boilers are effectively removing the need for the traditional, well-known and simpler form of domestic energy storage - the hot water tank* that can instantly heat water as it flows through the system and can provide domestic storage for **days and months** (see table in figure 19 below).

IRENA (2013) notes that state-of-the-art projects have shown that water tank storage is a cost-effective storage option and that its efficiency can be further improved by ensuring an optimal water stratification in the tank and the addition of effective thermal insulation.

This exemplifies the trade-offs with achieving one policy goal installing newer increased-efficiency condensing boilers, versus promoting the benefits and attractiveness of improved-capability hot water tanks that can act as significant potential demand side management assets within energy systems.

Figure 19: Typical Parameters of Thermal Energy Storage Systems

TES System	Capacity (kWh/t)	Power MW)	Efficiency (%)	Storage period (h, d, m)	Cost (€/kWh)
Sensible (hot water)	10-50	0.001-10	50-90	d/m	0.1-10
PCM	50-150	0.001-1	75-90	h/m	10-50
Chemical reactions	120-250	0.01-1	75-100	h/d	8-100

*** A combi boiler removes the need for a tank for reserve hot water. The combi-boiler heats to demand so provides a constant flow, therefore no tank is required.**

Box 6: Phase Change Material (PCM) Thermal Energy Storage e.g. SunAmp, UK

SunAmp Heat Batteries are a novel PCM product that has begun to penetrate the UK market. The product works by absorbing heat when melting occurs and releasing heat during freezing and can be stacked like lego bricks for easy storage (see below), with different types of heat batteries for storing heat at different temperatures.

20kWh, 30kWh, 40kWh and 150-200kWh storage solutions are all available, with the latter able to replace hot water tanks. An additional larger system of 3-5MWh is also available to store waste heat from products and processes such as refrigeration, waste process heat and anaerobic digestion.

Conventional heat inputs such as: CHP, Solar Thermal, Heat Pumps, Biomass, waste heat, off-peak electricity and district heat that are intermittent can be controlled and enhanced via use of heat storage, in a similar way to battery electricity storage. Enhanced use of heat via these products include:

- Reduced cycling
- Enhanced solar fraction
- 100% off-peak consumption
- Increased efficiency of up to 45% or more

Three products are available:

1. SunampStack which takes the storage capacity of a giant hot water tank into an appliance the size of a domestic fridge. This typically doubles the financial return on Air Source Heat Pumps and micro CHP (Combined Heat and Power) systems and provides heat and hot water whenever required.
2. SunampPV is designed to store excess electricity from a Solar PV array as heat. It can later deliver fast-flowing hot water on-demand. No need for a water tank or an immersion heater. And it works perfectly with combi boilers or instant water heaters (gas, oil, LPG or electric).
3. SunAmp cube (trial development currently in progress) which relates to large community-scale and commercial scale heat storage and will be able to deal with grid constraints by ensuring continuous generation. This will have a huge impact on project payback.

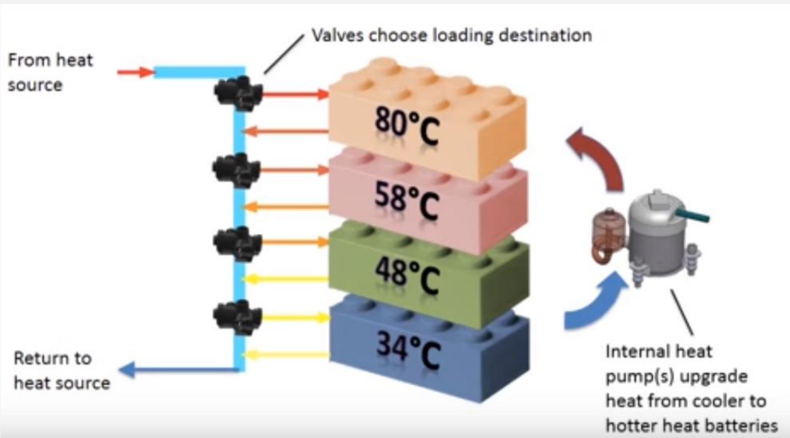

Figure 20: SunAmp product system design

A further assessment of barriers relating to thermal storage solutions such as these will continue to be carried out between July – October 2016.

Box 7: Political & Regulatory Barriers - Pumped Hydro Energy Storage

Pumped Hydro Energy Storage (PHES) assets such as Dinorwig and Festiniog were originally planned (in the 1960s/70s for providing grid flexibility, utilising extra generation overnight and providing support at peak hours during the day. These assets were designed for a daily pumped generation cycle and could therefore arbitrage between a substantial expected price spread. The introduction of CCGTs in the UK from 1991* resulted in a shrinking of these price spreads between day and night, causing PHES assets to no longer operate in an arbitrage mode. Most of the revenue therefore now comes purely from the provision of grid ancillary services. However, with increased wind and PV penetrations, wider price spreads could open up again, potentially re-creating the opportunity for PHES to operate in arbitrage mode i.e. 'mopping up' surplus energy and helping to meet peak demand at later times.

The main benefits of PHES are as follows:

- Offers a large strategic, energy reserve, fully controllable by the grid system over long periods of time with flexible use over days, weeks and seasons.
- Like conventional plant, PHES machinery consists of spinning mass that can therefore provide the inertial response that is currently at risk of provision as both renewables increase and conventional plants reduce.
- If required, PHES can be designed to provide Frequency (or Secondary Frequency) Response like Dinorwig.
- Can be utilised at full capacity - some more modern potential schemes e.g. Coire Glas** could run for up to 50 hours and could also offer a fully variable pumping speed drive*** (older models can't offer this).
- Rather than a daily cycle, the Coire Glas scheme (for example) could also provide 2 days of pumping and 2-3 days of continuous generation to assist the Grid with unpredictable/long-lasting weather cycles that might affect outputs from renewables.
- Can complement other forms of storage on the system e.g. PHES can provide high levels of power within 20-30 seconds, with up to 50 hours duration whilst batteries with shorter storage duration of 1-2 hours can provide power in less than a second.

However there are also a number of **considerations or drawbacks acting as a barrier** to PHES development:

- **Policy-risk and uncertainty** in relation to decarbonisation targets / future levels of renewables; and (related), the types of grid services required. Greater certainty would also provide a stronger case for investment due to the re-opened arbitrage spread associated with renewables noted above.
- **Recovering long-run marginal costs**
- **Positive externalities and missing markets** i.e. benefits and services that society requires but no means for paying for them
- **Market distortions –** e.g. competing services/technologies receiving subsidies

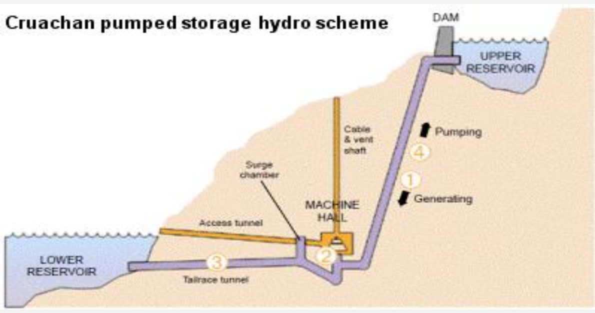

Figure 21: Cruachan Pumped Hydro

*Roosecote Station in Cumbria commissioned in 1991 producing 224,000kW with a thermal efficiency of 49%.
**Coire Glas is a PHES scheme initiated by SSE with planning permission but current regulatory & commercial setbacks
*** Older schemes have a pumping mode of either zero or full (no in between). In more modern schemes, that load can be fully

8 Key Messages & Recommendations

Section 1 and Section 7 have outlined five key messages regarding barriers uncovered so far, with related recommendations. A number of other barriers associated with system-wide energy storage options have additionally been assessed, although further analysis of barriers across all energy storage assets will be further uncovered post July 2016. Solutions to these barriers will also be considered.

A summary of themes that are likely to be included in the final report key messages are provided below:

1) There are a range of barriers that energy storage solutions currently face and these need to be recognised, considered and addressed.
2) Energy Storage solutions are not the only solutions that can provide key system services of flexibility, resilience and system security. These assets can compete with others as long as barriers are identified and addressed, and a level-playing field is sought.
3) Further research into the benefits of system-wide energy storage options are required, including in comparison to these aforementioned alternative options.
4) Competing options for electrical energy storage are well known, however alternatives to other types of storage e.g. thermal, gas and transport solutions have been assessed to a lesser degree and therefore deserve more of a focus.
5) System services such as flexibility, resilience and system security need to be better valued by adapting existing political, regulatory, financial, legal and commercial structures.