350PPM
Commercial Solutions to Climate Change

Grid-scale Energy Storage: the Need, the Technologies

Executive Summary

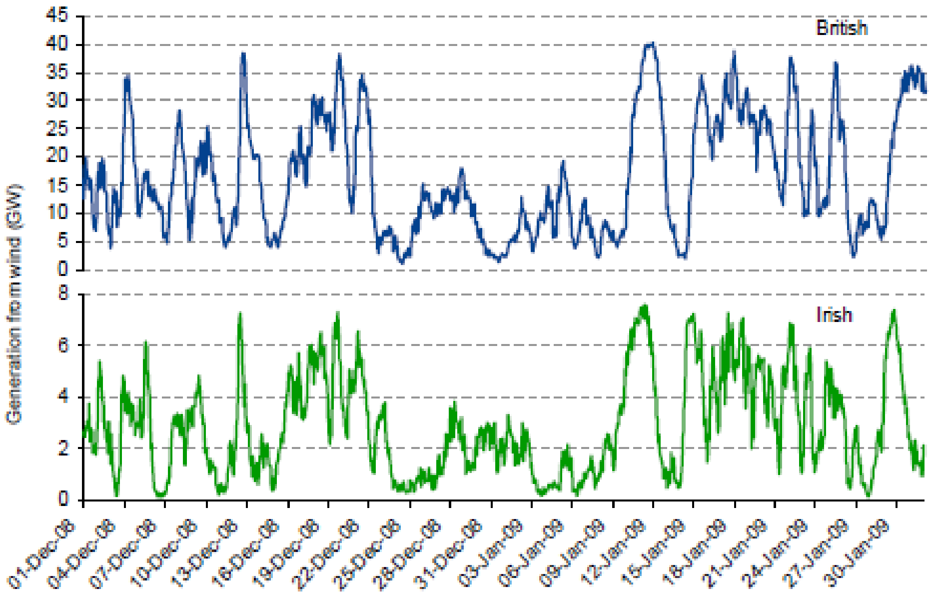
- Electricity supply in the UK and around the world is slowly shifting from fossil fuel sources to renewable ones.
- Most renewable sources are intermittent, only creating energy when the sun shines, or the wind blows.
- Consequently, we expect it to get much harder to match supply with demand.
- In this report, we examine this problem and outline possible solutions.
- These include the use of interconnectors, Demand Side Response (DSR), new fossil fuel power stations and grid-scale energy storage. These are all methods of providing flexibility in either demand, or supply, or both.
- We focus in on grid-scale energy storage as what we believe to be the most logical, versatile, environmentally-friendly and economic of these. We define grid-scale energy storage as storage that can provide power on the order of GWs (Giga Watts) and energy on the order of GWhs (Giga Watt hours).
- Grid-scale energy storage can both store excess electricity (when it is windy, for example), and provide supply when other sources may not be able to meet demand. We see this would allow for, and speed up, the adoption of renewables.
- The value of two key revenue sources for grid-scale energy storage are expected to increase – peak / off peak electricity spreads [14], and providing balancing and ancillary service to the Electricity Network Operator (National Grid in the UK) [16].
- Estimates for the total market value for energy storage in the UK out to 2050 are on the order of tens of billions of pounds [10,13,33].
- The market internationally is estimated to be 100 times the size [10].
- The market is estimated to increase a further 3-6 times if storage is used as baseload (constant supply) and 6-10 times with the full electrification of cars and heating [10].
- In our opinion, there are only two proven technologies which can provide economic grid-scale storage *today*, Pumped Hydro Storage (PHS) and Compressed Air Energy Storage (CAES).
- Note that batteries are not one of these.
- Pumped Hydro Storage (PHS) is expensive to build [27], and we believe there is limited opportunity to build more in the UK.
- We believe the only alternative is Compressed Air Energy Storage (CAES). New versions of CAES have been developed which are significantly more efficient (hence profitable) and do not burn fossil fuels [20].
- **350 PPM view grid-scale energy storage - particularly CAES - as a wholly credible candidate for the 'next big trend'. We hope to bring our investors opportunities in this area soon.**

The Problem – The Shift to Renewables

We might not think about it often, but most of us depend on a stable electricity supply system to provide us with the energy we need to run our lives. This system has to be able to cope with the peak energy demand from all its users, all the time. We expect this will become increasingly difficult to do.

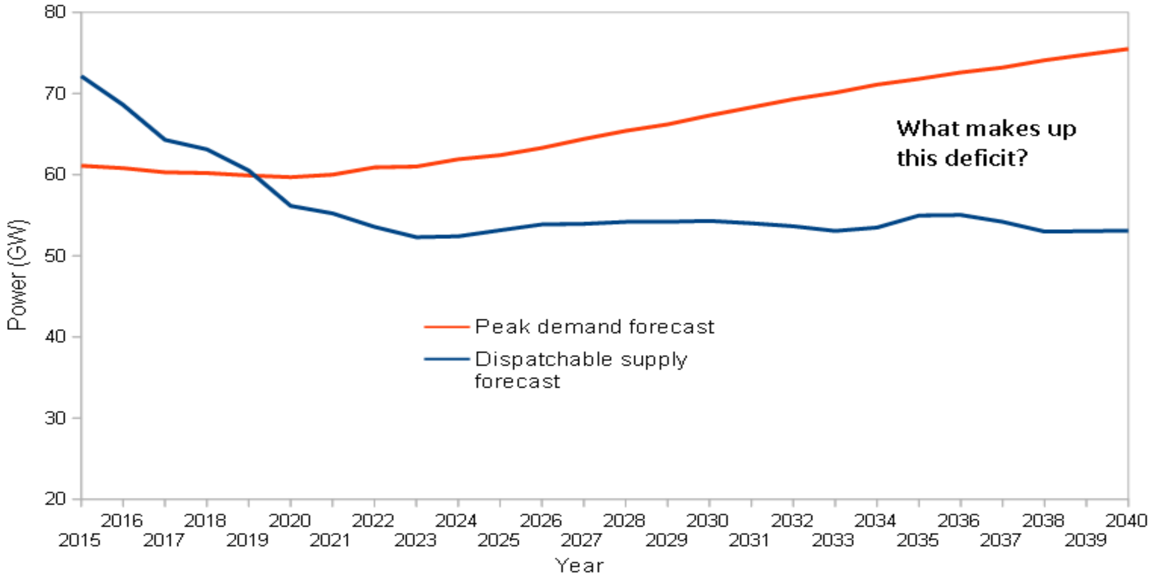
On the demand side, peak demand could rise significantly over the next few decades [2] as we switch to greener forms of energy - moving from petrol to electric cars, and from fossil fuels to electricity for heating, for example. This switch is government-mandated - as the UK attempts to meet international climate change targets - and increasingly seen as 'the right thing to do'. Even in the most conservative case, peak demand is unlikely to fall [3].

On the supply side, and for the same reasons, there is an ongoing shift from polluting fossil fuel sources - coal, oil and gas - to renewable ones, such as wind and solar, with wind being particularly relevant to the UK. This is only expected to continue in the future [4]. As a result of this, we believe we are mainly moving from **dispatchable** sources – ones that generate electricity when we need it - to **intermittent** ones, which only generate electricity when the wind blows, or the sun shines. **Graph 1,** below**,** highlights the scale of future intermittency in the UK**.** It shows that power output from UK wind farms in 2030 could vary by as much as 40 GW (gigawatts) on short time scales – which is a massive amount, roughly two thirds of the entire current peak demand [5].



Graph 1 – Example wind generation profiles for 2030 with the actual wind of 2008/9 [30]

Putting the supply and demand side trends together, we see that – *if nothing is done* - **dispatchable supply is expected to fall below peak demand**. See **Graph 2**, on next page.



Graph 2 - Forecast peak demand versus dispatchable supply (biomass, CHP (Combined Heat & Power), gas, coal, nuclear, not CCS (Carbon Capture and Storage) - due to cancellation), including fixed present day flexible supply (hydro, other storage, interconnectors). Based on the National Grid's Future Energy Survey 2016, Gone Green scenario [5].

Intermittent sources may make up the deficit some of the time, but this cannot be relied upon, as **Graph 1** demonstrates. Some other method must be found. Note there is a need for additional capacity margin to allow for breakdown of generation. At other times, as **Graph 1** again implies, supply is expected to exceed demand. **Currently, this energy cannot be stored on a large scale, as there is only ~3.2 GW of electrical storage in the UK (as of October 2016)** [6]. Sometimes, supply has to be curtailed, and is paid for the privilege [7]. Energy that could have been captured is, instead, wasted.

This is a problem that needs to be addressed today, as solutions will take time to implement.

Current + Proposed Solutions

There are a number of ways of dealing with this problem, now, and in the future, should the problem deepen, for example:

Buying and selling electricity through interconnectors with our neighbours. The need is such that we do this already, but, as an island, we are not well connected [8]. More would have to be expensively built, without any guarantee of solving the problem – it should be common sense that demand (people are up at the same time) and supply (**see Graph 1**, for example) tend to match up between countries. This method could also make us dependent on our European neighbours, which may not be possible, or desirable post-Brexit.

Matching demand to supply, by asking users to adjust electricity use when necessary. This is called Demand Side Response (DSR). It can be done automatically, but conceptually it is back-to-front, and the need is such that we do this already [15]. However, ~85% of demand is inflexible, and therefore cannot be adjusted to supply, and it is unlikely to be economically viable for *all* the remaining ~15% to participate [9].

Building new fossil fuel plants to provide the missing supply. This is likely to be an expensive, non-green solution. The plants - most likely gas-powered - would sit idle when not needed, and run inefficiently when switched on/off and ramped up/down to meet demand[10]. It is unlikely that anyone would suggest using a nuclear power plant like this.

Storing excess energy when produced. Using this same energy to provide the missing supply. Sound sensible? As explained above, this happens already in the UK, but to a limited extent. **The potential is there to massively increase our storage capacity here and worldwide.**

Note that storage can act on both supply and demand sides, as can interconnectors; the others act on one side alone. As the problem is considerable in scope, we are likely to need *all the solutions*, but of all the options, we believe **storage is the most logical, versatile, environmentally-friendly and economic.** And for innovative companies and their investors, potentially the most lucrative.

The Grid-Scale Storage Solution

The Requirements

Since we have identified the concept as sound, the next question is, can we do it in practice? We believe the following attributes are required:

The energy storage must be employable on the same scale as the problem: grid-scale. Quantifying exactly what this means is difficult as it involves speculation about future demand and supply profiles. There is no consensus. Our simple analysis of **Graph 2** shows a need for ~20 GW of flexible supply by 2040. Based on the same numbers, the National Grid see up to 15 GW of this being fulfilled by storage by 2040 [11]. Storelectric, a UK storage company (purveyors of Compressed Air Energy Storage (CAES), see below), see a need now in the UK for 5 GW of storage and for 17-20 GW by 2050 [10]. The UK government's Technology Innovation Needs Analysis, 2012, sees a central case of 27.4 GW storage need by 2050 [13]. In summary, it is not unreasonable to suggest a need for storage **on the order of GWs, growing to tens of GWs** out to 2050 in the UK. Scaling up internationally, the need is therefore on the order of TWs (Tera Watts) .

The storage also needs **sufficient duration at rated capacity -** total energy capacity in other words - such that it can time-shift energy across a significant proportion of the day. It should be common sense that seconds and minutes are not sufficient. One benchmark used is **~5 hours** [13]. This is roughly the length of the peak electricity period in the evening.

The storage should also be **efficient** and retain as much energy as possible between charge and discharge. And it should remain efficient over its lifetime, which should be as long as possible. For short term grid services, the storage also needs a quick enough response time.

Revenue

As well as possessing these requirements, the storage must be able to provide them economically. Storage has three main revenue streams, two of which we believe are increasing in value:

Buying electricity at off-peak prices and, using the above time-shift capability, **selling at peak prices**, which are on average double. As a direct result of the increase of renewable use, the **spread between the two is growing, and this trend is expected to continue** [14]**.**

Providing balancing and ancillary services to the Electricity Network Operator (National Grid in the UK). For example, reserve and frequency response services. National Grid confirm that the **volume and value of these services is on an upward trend** [16]. Energy research firm Aurora see ancillary services increasing in value out to 2030 [17].

The Capacity Market, a government subsidy aiming to ensure the security of the UK's electricity supply [28].

Market Size

Given these economics, what about the potential market size? Indications include:

The UK government's 'Technology Innovation Needs Analysis', 2012, sees 'value in business creation' due to energy storage of **~£11.5 billion** from 2012 to 2050. It also sees 'value in meeting emissions targets at low cost' of ~**£4.6 billion**. Both of these are central cases, with the upper limit considerably higher [13].

The National Infrastructure Commission Report 'Smart Power', 2016, projected a possible **£8 billion** saving to the UK, per year, by 2030 if storage and flexibility measures are introduced on a large scale [31].

Most relevant perhaps, Storelectric - the UK storage company mentioned previously - quote a figure of ~**£16 billion** for the value of the UK energy storage market over the next 10-15 years [21]. They see the **international market as being 100 times the UK market**. In addition, they estimate that the storage market expands by **3-6 times** if storage is used as baseload (constant supply), rather than simply coping with renewable peaks, and a further **6-10 times** with the full electrification of cars and heating [10].

Grid-Scale Storage Technologies

We believe there are **only two proven technologies** that can provide this specification of grid-scale storage today. Batteries are not one of them (see below). **Both technologies can be 100% renewable and can enable the use of renewables.**

Pumped Hydro Storage (PHS) is expensive to build[27] and there is little opportunity to build more in the UK[22], due to topographical limitations. PHS works by pumping water against gravity, then regenerating it by allowing water to fall through a turbine. Most of the world's current energy storage capacity is PHS [23]. Consequently, this is a relatively mature market, with, in our opinion, little room for technological improvement and direct investor involvement.

Compressed Air Energy Storage (CAES) is, we believe, the only current alternative. It is significantly cheaper than PHS to build [27]. CAES stores electricity by compressing air into large underground spaces such as salt caverns, aquifers and depleted oil fields. Air is expanded through a turbine to regenerate the electricity when needed. It has been in use safely and reliably since 1978 in Germany (321 MW) and 1991 in America (110 MW) [24], but is experiencing a renaissance. This is due to the above revenue stream improvements, and the development of new technology **which increases the efficiency** of CAES plants from 42-54% (electricity out to in), to ~70% [24] . This increases potential profitability. This advance, known as **adiabatic CAES**, is also **100% renewable**, whereas existing plants burn gas. In the UK, Storelectric are the only company we are aware of with the technology and ambitions to build an adiabatic CAES plant in the near term.

But what about batteries?

Most existing battery storage projects can only store/generate power of the order of tens of MW, for durations of tens of minutes max[25]. **This does not match the specification above**. Batteries current use is limited to quick-response, short-duration applications. Costs are one issue, which are falling, but are not expected, for example, to make lithium ion batteries viable until 2019 at the earliest, with the consensus at 2027, though, on historical learning rates, further out still [12]. Batteries also have lifetimes on the order of a 1/3 that of a CAES plant, and efficiency tends to go down over the course of this life, whilst CAES plants can operate near peak efficiency their whole life [26]. Even Tesla, having just announced the development of a 100 MW battery, are not sure they can actually make it [29]. This is not an issue with PHS or CAES at 500MW+. We know these can be built. They exist already on a similar scale, as explained in the previous section.

But what about distributed storage, or hydrogen storage?

Distributed storage is already used to some extent. In the future, it is certainly possible that one day we all use our electric cars as one distributed storage device (known as 'vehicle-to-grid'). And it is certainly possible that each of us ends up with a small battery in our smart homes. Would these solve the problem? Unlikely on their own, as we believe you would still need the grid and grid-scale storage for backup, and how do we cope before distributed storage takes off, if ever? We believe the two do and will co-exist quite happily.

Over decades, we could well transition into the 'hydrogen economy'. We may all drive around in hydrogen cars - rather than electric ones - and we may pump hydrogen around our existing natural gas lines and heat our homes with the stuff too. Under these circumstances, it may make sense to store electricity in hydrogen form (known as 'power-to-gas'). Currently, hydrogen storage is only really under development for cars, and efficiencies are low [10].

But what about X, and what about Y?

This is a short report and we have not covered all possible storage technologies. No-one knows if any of these as yet unproven technologies will ever be able to meet the sheer scale of the challenge and do so economically. But when there are proven, profitable, 100% renewable options available today, we may not need to know. **There are technologies and companies that are investable now, and here at 350 PPM, we hope to bring you one of these opportunities very soon.**

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Notes + References

[1] National Grid's Future Energy Survey 2016 (note that this was written prior to the 2017 version coming out)
At the following link, the download can be found under the section 2016 Future Energy Scenarios, 2016 FES:
http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/FES/Documents-archive/

[2] See [1], page 34, 'Gone Green' scenario.

[3] See[1], page 34, 'Slow Progression' scenario.

[4] See[1], chapter 4.

[5] See[1], the numbers used come from the worksheet version of Figure 4.1.2, page 88.

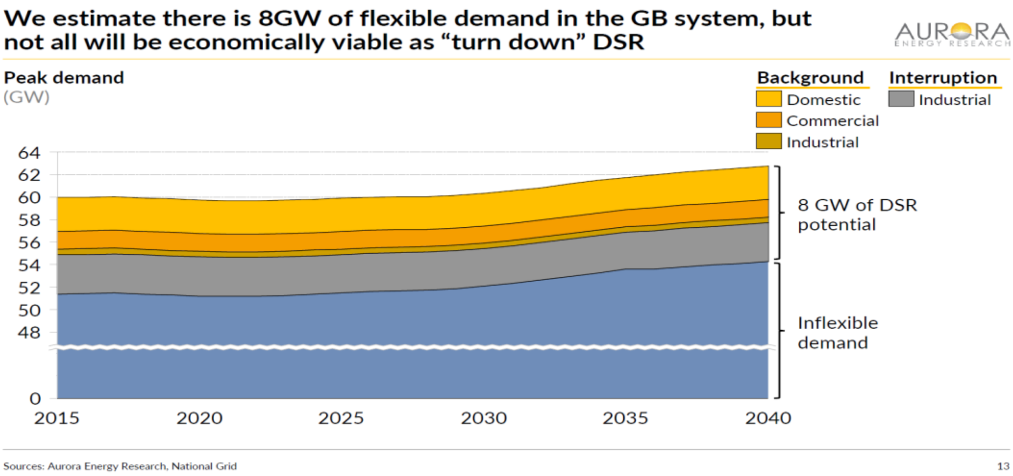
[6] https://www.r-e-a.net/news/new-data-shows-extent-of-existing-energy-storage-deployment-and-planned-projects-in-the-uk

[7] See, for example, http://www.dailymail.co.uk/news/article-2088196/Wind-farms-paid-25million-NOT-produce-electricity-blustery.html

[8] https://www.publications.parliament.uk/pa/ld201415/ldselect/ldsctech/121/IMG00010.GIF

[9] http://powerresponsive.com/wp-content/uploads/2017/05/Aurora-Energy-Research-Investor-Event.pdf

The graph referenced is this:

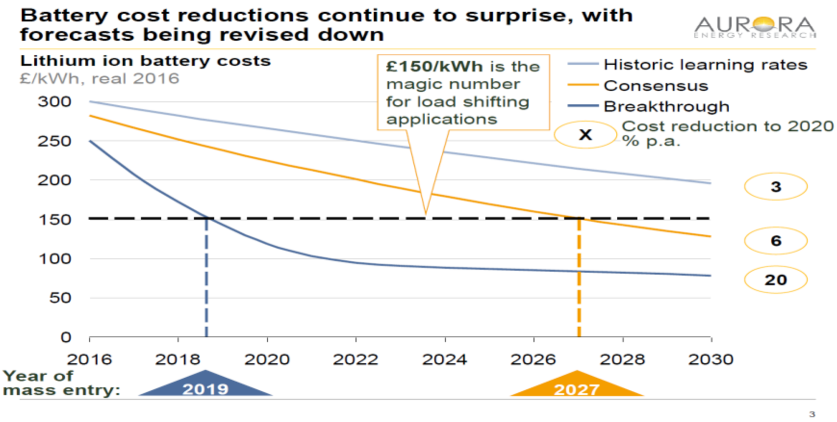


[10] http://storelectric.com/energy-storage.html

[11] See [1], section 4.3.

[12] http://powerresponsive.com/wp-content/uploads/2017/05/Aurora-Energy-Research-Investor-Event.pdf

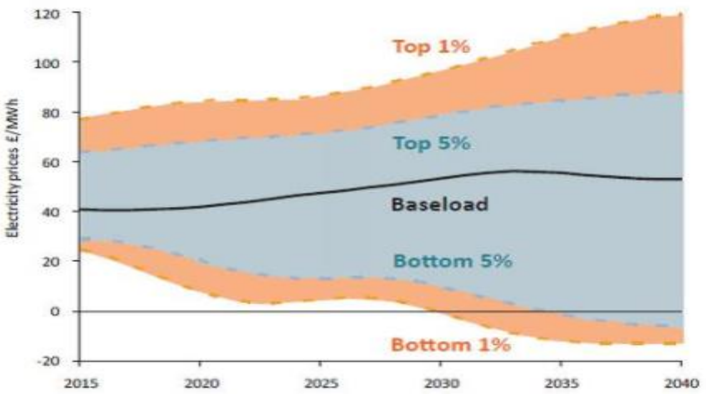
The graph referenced is this:



[13] UK Government's Technology Innovation Needs Assessment (TINA), 2012
http://lowcarboninnovation.co.uk/working_together/technology_focus_areas/electricity_networks_storage/

[14] https://policyexchange.org.uk/power-2-0-the-policy-exchange-smart-power-report-in-7-key-charts/

The graph referenced is this:



[15] See [1], section 3.5.1.

[16] National Grid System Operating Framework (SOF) 2016, 1.2 Key Messages: "Distributed generator outputs and interconnector flows increase in size and variability throughout the decade assessed for SOF 2016. Large generators and other interconnectors will have to operate more flexibly to accommodate this, complemented by growth in balancing tools and technologies such as energy storage and flexible demand."
http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=8589937803

National Grid Future Energy Scenarios, 2016, section 5.3 "The sensitivities all show that flexibility and balancing requirements on the gas and electricity systems will increase from today's level."

At the following link, the download can be found under the section 2016 Future Energy Scenarios, 2016 FES:
http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/FES/Documents-archive/

[17] http://powerresponsive.com/wp-content/uploads/2017/05/Aurora-Energy-Research-Investor-Event.pdf

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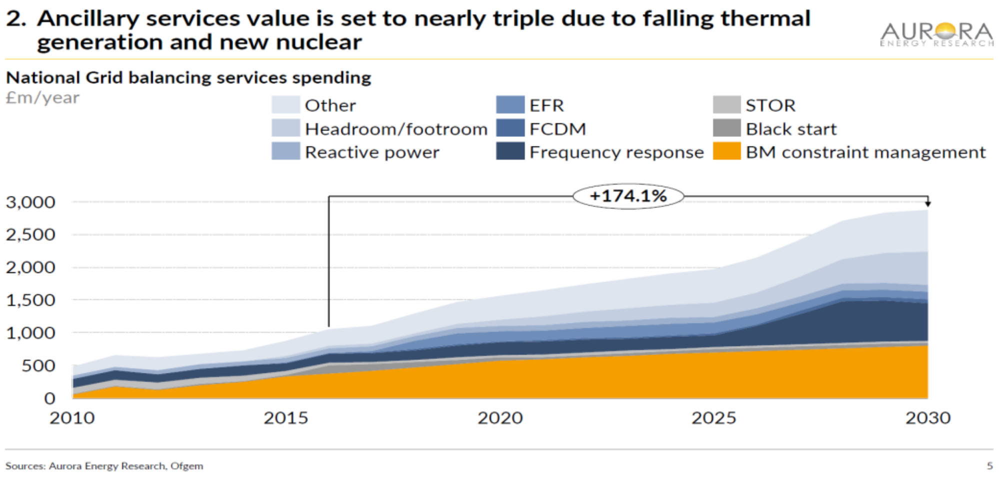

[18],[19] Not used.

[20] http://storelectric.com/index.html

[21] http://storelectric.com/faq.html

[22] Current + planned hydro projects are detailed in:
https://www.ice.org.uk/getattachment/knowledge-and-resources/briefing-sheet/pumped-hydro-storage-and-the-coire-glas-scheme/Briefing-Sheet-Pumped-Hydro-Storage-in-format.pdf.aspx

[23] See, for example the US Department Of Energy's Global Energy Storage Database.
http://www.energystorageexchange.org/projects

[24] For existing plants, this can be verified by visiting the US Department Of Energy's Global Energy Storage Database. If you filter the technology by Technology Type 'Electro-mechanical', and status 'Operational' the two mentioned CAES plants will be found. Efficiency statistics are given.
http://www.energystorageexchange.org/projects

For the Storelectric efficiency number, see [20]:

[25] This can be verified by visiting the US Department Of Energy's Global Energy Storage Database. If you filter the technology by Technology Type 'Electro-chemical', and status 'Operational' it can be noted that the largest battery projects are on the order of 10s of MW, with durations mostly on the order of minutes.
http://www.energystorageexchange.org/projects

[26] http://www.apexcaes.com/technology-overview

[27] Relative costs PHS versus CAES can be found on page 23 of the following:
http://www.ecofys.com/files/files/ecofys-2014-energy-storage-white-paper.pdf

[28] For a brief introduction to the Capacity Market see the opening paragraph of the following:
http://business.engie.co.uk/wp-content/uploads/2016/07/capacitymarketguide.pdf

[29] Saturday Telegraph, 15/07/17, Business Section.

[30] 'Impact of Intermittency: How wind variability could change the shape of the British and Irish Markets', 2009, Poyry.
http://www.poyry.com/sites/default/files/impactofintermittencygbandi-july2009-energy.pdf

[31] National Infrastructure Commission Report, 'Smart Power', 2016, page 7:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505218/IC_Energy_Report_web.pdf

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