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The future of Electricity Storage

Author / Contact :

Julian Stringer
jules@teignenergycommunities.co.uk

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Section 1. Background

This document considers the current state of the electricity storage market and how it is likely to develop in the future.

Decarbonising the electricity is essential if the UK is to meet legal commitment to be carbon neutral by 2050. This means that existing fossil fuel burning generation needs to be replaced.

Storage already has a role in providing a fast response to stabilise the network. It is now law that the UK should be net zero carbon by 2050. This means that energy must come from zero carbon sources by then. Currently zero carbon energy sources are either nuclear or renewables. Wind and Solar renewables are now cheaper than nuclear, so these should be used as far as possible but there is a problem when the wind doesn't blow, the sun doesn't shine and so on. This gap could be filled by storage, other renewables such as tide, wave and hydro or nuclear.

The new Zero Carbon Britain (ZCB) report from the Centre for Alternative Technology (CAT), suggests that 89% of UK energy could be supplied from renewables, with demand side management. The remaining 11% comes from storage in various forms:

- Pumped storage
- Batteries
- Heat Storage
- Hydrogen
- Biogas and Synthetic gas (for longest periods)

In this paper I have used the ZCB report as a basis for estimating the scale of the amount of storage that might be needed, though I make considerable mention of the report, that does not mean that it is achievable. The changes required to achieve ZCB are larger than those required by our own Zero Carbon report, which in turn are going to be difficult to achieve.

It is our considered view that a reduction in everyone's energy consumption is needed to achieve the reductions required in order to prevent temperature rise above 2˚C, let alone 1.5˚C. A technology only solution is not sufficient on its own.

Storage can be used in a number of locations in the network:

- Behind the meter:
  - in domestic or commercial premises to maximise use of onsite generation
  - in domestic or commercial premises to gain from differential tariff or other incentives
  - at generation sites to release energy when it is most advantageous to do so.
- In front of the meter to:
  - Perform a number of short-term functions which are detailed later
  - At network nodes to provide buffer storage, so that better use can be made of transmission and higher voltage distribution capacity.

Demand side management is a part of enabling the transmission and distribution network to cope with variable supply and demand. This is a substantial topic in its own right and is only mentioned here because the ZCB report relies on it to increase the possible proportion of renewables. Demand side management is discussed briefly later in this document.

Section 2. The current situation and the imminent problem

Historically the electricity network has developed to handle peak demand, yet we know that this only occurs for about 3 hours per day. This means that currently the system can handle peak demand of 61GW, but averages 34.21GW. If demand could be time-shifted without increasing peak-demand then increased demand could be met within limits. At the time of writing the capacity of the network is 103GW[1]. Elsewhere we have estimated that average demand could rise to 72GW if nothing were done to reduce demand from full electrification of domestic heating and full EV take-up. This is equivalent to 628TWh of electricity, if measures are taken to reduce domestic heating demand this could be 457TWh. If demand is not buffered in some way this could mean a peak load of 242GW, this is not feasible. A number of things could happen:

- Existing houses do not take up electric heating en-masse, remaining with some form of gas.
- Existing houses are retrofitted with sufficient insulation to reduce their energy use for heating: Insulate, Heat pump, Heat store
- Domestic storage becomes economic – either using EV batteries or static storage to store energy when it is cheap and release it at peak time, probably for domestic use, though feed into the grid is a possibility.

Currently Nuclear provides a steady baseload of 9.4GW, this cannot easily be turned up or down.

Renewables (solar + wind) could be expanded to meet most of demand most of the time[2], but will only be able to do this all of the time is there is excess capacity. This means that there is a need for capacity that is easy to switch on when solar and wind fail to meet demand, this may not be nuclear. New nuclear plant is extremely expensive to build, so the price that must be paid for new nuclear generation is higher than for wind or solar. Existing nuclear plant that has already been built generates at lower cost, but with well known risks. The characteristics of nuclear mean that it is not an ideal complement to renewables, but storage could play a part with nuclear to charge when supply exceeds demand.

What can fill in the gap when wind and solar do not generate sufficient?

- Natural gas peaking plant
- Biomass generation
- Generation from waste
- Storage
- Demand side response.

There are several electricity network related issues:

- Smoothing out demand over the daily cycle
- Supplying energy when no renewable source is generating
- Dealing with network instability caused by intermittent supply.
- Transmission and distribution of renewable energy, particularly off-shore wind

[1] https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx#:~:text=The%20UK%20has%2015%20reactors,reactor%20designs%20and%20their%20siting.

[2] CAT Zero Carbon Britain report is based on an hour by hour computer simulation of the electricity network using weather data collected over a 10 year period. This showed that renewables could be expanded to cover 74% of demand, and if sufficient storage were used 89% of demand could be covered.

Smoothing out demand over the daily cycle could be handled by behind the meter storage at consumer sites. A typical all electric house with electric vehicles, electric heating could consume 50kWh on a cold winter day. If the house is well insulated heating can be shifted by one or two hours to avoid the peak 3 hours, a battery of about 10kWh capacity should hold enough to avoid use at peak times, particularly if heating and vehicle charging are avoided during peak hours. Shifting demand from peak hours is a bit simplistic because it could just result in shifting the peak. A possibility is for a dynamic tariff, but to be effective that would require management software at customer sites to use it effectively, which in turn leads to unfairness when customers do not have or misuse such software.

Daily cycle smoothing could also occur at LV substation level.

The electricity market that has developed around these issue is complex, participants can participate in a number of different markets, the revenue stack includes:

- Balancing market
- Frequency response
- Voltage response
- Reserve
- Transmission constraint management
- Wholesale price arbitrage
- Capacity market (currently suspended)
- Resilience (brown-out , black start)

Participation in these markets can be planned day ahead or real-time response.

The calculation of how to deploy plant has given rise to companies such as Habitat energy offering optimisation services.

Storage can respond more quickly than other types of generation, which has made it suitable for frequency and voltage response for some time. This has recently led to significant investment in storage.

Section 3. New CAT Zero Carbon Britain report

CAT have now published a revised zero carbon Britain (ZCB) report. They have constructed a model which demonstrates how UK energy demand could be satisfied without fossil fuels.

They have constructed an hourly energy model using hourly weather data for a 10 year period 2002 – 2011 to simulate supply and demand over the period using the mix of supply described here. Ideally ZCB modelling should be replicated over different and more recent time periods, but this will involve a significant effort.

ZCB assumes annual energy demand reduced to 815TWh per year from 1,670TWh/year for 2017[3]. This reduction includes domestic, transport and industry. The biggest reductions come from buildings and transport. Transport is reduced by some behaviour changes:

- Using public transport in place of private vehicles
- Using Active travel modes where possible
- Exchanging petroleum powered vehicles for electrically powered ones.

[3] Zero Carbon Britain: Rising to the Climate Emergency: Power Down Summary, page 39

The TECs Zero Carbon Report only assumed reductions from domestic buildings and light transport, leaving heavy transport and industry unchanged, this showed an increase of 52.63%[4] in electricity demand, with a drop in total energy demand to 1070TWh from 1647TWh, which resulted in a GHG reduction of 71.42%. ZCB includes all transport and industry and so reduces energy use and emissions still further. Both scenarios are on the extreme of what might be achieved.

ZCB analyses a scenario where electricity production is as follows:

Technology	**Energy (TWh per year)**	**Details**
Electricity		
Offshore wind	530	140GW maximum power , 14,000 turbines rated 10MW
Onshore wind	77	30 GW maximum power, 15,000 turbines rated 2MW
Wave power	25	10 GW maximum power
Tidal (range and stream)	42	20 GW maximum power
Solar PV	74	90 GW maximum power, covering 15-20% of UK roof area)
Geothermal Electricity	24	3 GW maximum power
Hydropower	8	3 GW maximum power
Total Electricity	**780**	
Renewable Heat		
Solar Thermal	25	Around 3% of UK roof area
Geothermal Heat	15	
Ambient Heat	135	Extracted from air, ground and water source heat pumps
Total Renewable Heat	**175**	
Biomass		
For biogas and carbon neutral synthetic gas	74	From Waste (36 TWh) and grasses for anaerobic digestion (38TWh)
For carbon neutral	115	From Miscanthus and

[4] Comment after table 4.4

synthetic gas		Short rotation coppice
For heat	41	From Short rotation coppice and short rotation forestry
Total Biomass	**230**	
Total Energy	**1,185**	

Table from page 61 of zero carbon Britain report

The ZCB report's 780 TWh of electricity exceeds our calculated electricity demand.

To balance supply the ZCB proposes the following:

Duration / type	Technology	Capacity (GWh)
Demand side response	Shifted consumption such as EV charging times	500
Heat storage	Heat storage	200
Short term storage hours – days	Pumped storage, Batteries.	200
Hydrogen	Electrolysis using excess electricity at a maximum power of 25GW, most of this is used to produce Synthetic gas	20,000
Weeks or months	Biogas and Synthetic Gas	80,000

Gas engines would still be used to generate when there were insufficient renewables, but this would be using biogas.

Using the ZCB hourly model renewables meet demand 74% of the time, with demand side response this rises to 89%.

This means that there are between 45-70GW of gas power stations powered from renewable gas on the network.

Section 3.5 of the ZCB report describes the above in much more detail.

From the viewpoint of storage ZCB works if we have 200GWh of storage (battery + pumped hydro) on the network. Generally, storage is quoted in GW, so to compare with current storage forecasts some assumptions about duration are required. Currently installed storage is designed for short term use, so has a duration on about an hour, if the market remains the same then simply 200GW of storage will be required. If, however, there is more incentive to provide longer term storage then the average duration is likely to increase. Tesla Megapack modules can be configured with 2 hours duration, Cryogenic and Flow batteries generally longer. If we assume 2 hours is achievable in a benevolent environment, then 100GW is required, how long will it take to get there? Next is some examination of the current state of storage.

Section 4. Market forecasts for grid level storage

4.1 UK battery storage project database report

The UK battery storage project database report from Solar media analyses existing and planned projects, their report produced in April 2020 shows that currently there are 1GW of live battery storage projects and a pipeline of a further 13.5GW

Project status	Inverter power (GW)
Live	1
Ready to be built (planning approved and connection approved	1.3
Planning approved	5.7
Proposed/in planning	6.5

4.2 REGEN analysis

REGEN's latest analysis shows that there are 18GW of shovel ready renewable and storage projects with a pipeline of 61GW made up as follows:

Generation type	Pipeline power (GW)
Offshore wind	31.7
Onshore wind	11.9
PV	8.6
Storage	8.5

REGEN's analysis is based on registers of accepted to connect, rather than planning permissions used by Solar Media.

4.3 Capacity and duration of storage projects

Unfortunately, neither of these sources gives the energy storage capacity or duration for the storage facilities surveyed. I have found details of a significant proportion of projects from online research which give this detail the following tables show the aggregate details for these projects:

Year	2018	2019	2020	2021	2022
Duration (hours)	1.09	1.06	1.47	0.96	2.38
Power (MW)	153.6	104	149	67	400
Storage (MWh)	167.49	110.10	219.00	64.00	950.00

The sources used for the above are:

- Gresham House Energy Storage Fund PLC Interim Report page 11
- Gore Street Energy Storage interim report page 8
- National Infrastructure large projects
- Cleeve Hill Solar Park
- Oxford Energy Superhub

- Whitelee Wind Farm
- Holes Bay Energy Storage
- Pilsworthy Landfill
- Trafford Energy Park
- BYD projects for Zenobe
- Rock Farm battery storage unit

Most of these have lithium battery storage, but Oxford Energy Superhub includes 2MW/5MWH of flow batteries and Pilsworthy Landfill and Trafford Energy Park are cryogenic storage.

I have assembled these details in a spreadsheet StorageSchemes.xlsx which also includes many more projects where fewer details are known.

4.4 Standard Storage Modules

Several manufacturers now offer standard storage modules:

Manufacturer	Product	Technology	Inverter Power(MW)	Storage (MWh)	Duration (hours)
Tesla	Megapack	Lithium	1.5	Upto 3	2
BYD		Lithium	1.26	1.34	1.06
Invinity	VS3	Vanadium Flow Battery	78kW – 10MW	220kWh-40MWh	2 – 12

4.5 Co-located Storage and Generation

Many of the projects in the spreadsheet have storage co-located with generation. Storage is associated with both renewable generation and fossil fuelled plant. This has advantages to the generator:

- Storage can be used to allow generation to be continued when otherwise it would have to be turned off because of network constraints.
- The site manager can export stored energy when the wholesale price is high and store it when the price is low.
- Gas engines can run for longer once started, which is more efficient.
- The grid connection is better used.

Several sites are existing wind farms or solar parks that are being updated to include storage and the other technology.

Currently about 3.2GW storage is connected to the network the majority being pumped storage, currently 800MW is batteries mostly Lithium-ion.

In 2018 the Renewable Energy Association (REA) listed 39 UK Energy storage projects.

In 2016 the National Grid FES forecast between 3.6 and 18GW of network connected storage by 2040. Regen forecast a steady growth with at least 5GW by 2025, 10GW by 2030 and 15GW by 2040.

https://www.mordorintelligence.com/industry-reports/united-kingdom-energy-storage-systems-market-industry estimates a **Compound Annual Growth Rate** (**CAGR**) of 12% between 2019 and 2025 for energy storage capacity in the UK.

4.6 How long before we have 100GW of storage

Using CAGR of 12% on top of known capacity of 1GW it will take until 2061 to reach 100GW. This seems pessimistic. National grid's estimate of 15GW by 2040 requires a CAGR of 14.5% and 5GW by 2025 requires 37.9%, at 2025 this means a build rate of 1.4GW per year at 2025, if carried on further 100GW would be reached by 2035. I don't think CAGR is a good model to predict storage as this would require a build rate of 30GW a year at 2035.

It would be reasonable to assume that the current pipeline of between 8.5 and 13.5GW would be built by 2025, and that that rate could then continue for as long as needed. 8.5 in 5 years means 100GW would be reached by 2079 with 1.7GW installed per year. And 13.5 in 5 years means 100GW would be reached by 2054 with 2.7GW installed per year.

If we set a target of 2040 to have 100GW of storage, then we need to build 5GW of storage per year. But to achieve ZCB's ambitions by 2040 we also need:

Technology	Currently installed	Required 2040	Build rate GW/Year
Offshore Wind	10.14	140	6.49
Onshore Wind	14.10	30	0.80
Wave	0.00	10	0.50
Tidal (range and stream)	0.00	20	1.00
Solar PV	13.37	90	3.83
Geothermal	0.00	3	0.15
Hydro	1.90	3	0.06
Storage	1	100	4.95

In 2019 1.6GW of new offshore wind came on line and about 300MW of storage came on line. If enough storage is to be built to meet the ZCB scenario by 2040, then the current pipeline will need to be built in under 3 years and that rate of build will need to continue until 2040.

Offshore wind is a more established technology so ramping up its build rate from 1.7GW to 6.5GW seems more challenging. Also Offshore wind needs to be transmitted to demand locations.

4.7 Domestic Storage

Feed In Tariffs no longer apply to domestic renewable installations. Most domestic installations are PV, which generates during daytime. Commonly consumers are not at home during the day, which leads to electricity being exported with little benefit to the consumer.

A domestic battery can store electricity during the day so that it can be used in the evening when it is needed.

Domestic batteries and management software have been available for some time. Domestic batteries vary in capacity between 2kWh and 13.5kWh, and can cost up to £7,000 including installation.

With a time of use tariff, now possible with smart meters, a battery could be charged at the lowest tariff and discharged at the highest. This could help cost justify a battery.

Section 5. Technologies

Storage has many forms:

- Pumped storage
- Gravity stores
- Flywheels
- Chemical storage:
    - Hydrogen from electrolysis using surplus renewables
    - Methane (see CAT for details)
- Compressed air:
    - Underground in salt caverns
    - Cryogenic storage – Highview Power
- Lithium-ion batteries
- Flow batteries

Most of these technologies are only practical for grid level storage, but Lithium-ion is also a domestic option.

5.1 Demand side management

Demand side management isn't a storage technology, but could make use of storage.

Demand side management has a significant role to play in matching supply and demand. This includes:

- Large consumers turning down demand on command.
- Managing charging of EVs and domestic batteries
- Managing charging of heat stores

In order to make demand side management work suppliers will need to make this attractive, some possibilities are:

- Setting time-based tariffs which shift consumer demand away from peak periods

Sending signals to consumers to control when demand occurs, and offering incentives for obeying the signal

5.2 Pumped Storage

Suitable sites for pumped storage are scarce. The National Infrastructure Planning database for large projects only lists on pumped storage site Glyn Rhonwy Pumped Storage.

5.3 Gravity Stores

Gravitricity are building a pilot gravity store near Edinburgh.

If this pilot is successful a 4MW project in 2021.

5.4 Flywheels

In 2017 a consortium including the University of Sheffield was formed to produce a flywheel based system for fast response. This will eventually be capable of providing 1MW and store 20kWh.

5.5 Hydrogen from Electrolysis

Historically the cheapest way of producing hydrogen was from natural gas. It is said that by 2030 electrolysis will be cost effective. ITM Power now has a plant in Sheffield capable of producing 1GW of electrolysers per year.

Hydrogen is light and difficult to store, so would need to be compressed for practical storage. There is currently no suitable infrastructure for its distribution, though it can be added to existing gas supplies in small proportions.

Hydrogen can be stored over long periods.

This hydrogen could be used:

- Stored at renewable generation sites and used to power generators at times of low renewable output.
- To fuel large vehicles, ships.
- Converted to synthetic methane.

5.6 Biogas and Synthetic Methane

Biogas is produced from Anaerobic Digestion from the decomposition of biomass.

Synthetic methane is made via the Sabatier process. Hydrogen from electrolysis and CO2 (from burning biomass or from biogas) are combined to produce methane.

These can be used to:

- Power backup generators
- To supply energy intensive industrial processes
- As a replacement for Natural Gas

5.7 Compressed air

Underground Salt caverns

Here air is compressed and stored underground under a cap of water.

Cryogenic storage – Highview Power

Highview power has been developing cryogenic storage over the last 15 years. In 2014 it raised funds via a venture capital trust, and more recently Sumitomo Heavy Industries invested $46M, valuing Highview Power at $330M.

Highview Power's technology is established and in developing large scale projects:

- 350kw demonstrator
- 5MW/15MWH in the Manchester area
- 50MW/250MWH in the north of England live by 2022

5.8 Lithium-ion

Lithium batteries are most effective when delivering a lot of power over a short term, so the duration of most large scale grid scale plant currently being built is between 1 and 2 hours.

There are plans to build UK Gigafactories which will produce 30GWh per year of cells mainly for electric vehicles, but diverting 10GWh to grid storage at least sounds feasible.

The price of Lithium-ion batteries has dropped substantially over the last decade, and is forecast to drop further by 2025.

There appear to be 2 measures that can be a bit confusing:

- The price per MWh of supply – this is for comparison with other sources of generation.
- The price per kWh of storage.

According to BloombergNEF the supply price of 4 hour Lithium-ion storage has dropped from $800/MWh in 2012 to $187/MWh in 2019. In a different article they forecast that current prices will halve by 2030.

In 2019 battery prices were about $156/kWh, which is forecast to drop below $100/kWh by 2023.

British Lithium has found substantial Lithium deposits near St.Austell and has a grant from Innovate UK to develop Lithium extraction from hard rock, and aims to supply a quarter of the Lithium demand from the expansion of EVs by 2030.

Cornish Lithium is exploring extracting Lithium from geothermal waters.

Though Lithium-ion batteries have been expensive, and seen as suitable for short term storage, there has been substantial investment in production recently, primarily in conjunction with EVs. This effort could lead to market dominance against other technologies that we more suited to long term storage.

A downside of Lithium-ion batteries is that performance deteriorates with the number of charging cycles performed. There are hints that research from Tesla has developed a car battery pack capable of 1 million miles, so may have significantly increased the cycle limits. There are also report that energy density will increase to 400Wh/kg. Also the Tesla has applied to become a UK utility supplier.

5.9 Flow batteries

A number companies have been developing flow batteries for some time, these startups have found it difficult to raise funds to get to a marketable product. RedT is such a company which in 2019 was near to insolvent, but now has some projects lined up including the Oxford Energy Hub.

Avalon was a Canadian company that has already shipped flow batteries and has about 160 flow battery installations worldwide, in 2019 these merged to form Invinity , which has raised capital on the AIM market. This is the only quoted flow battery company.

Oxford Energy Hub

The Oxford energy hub includes:

- 50MW of Lithium-ion batteries
- 2MW of Vanadium reflow batteries
- Electric vehicle charging
- Low carbon heating for 300 homes
- Smart energy storage management

Flow batteries do not have the same cycle limitations as Lithium, so here the 2MW reflow battery front-ends the Lithium battery so that small demands are not passed to the Lithium battery.

Section 6. Conclusions

Storage is already commercially viable for short term applications. Technologies are in different states of development. It remains to be seen if the level of investment in Lithium based technology will lead to market dominance against other technologies that are less developed and in some cases have significant advantages. Given that Lithium battery prices are likely to drop significantly in the next few years grid level storage of at least 4 hour duration from Lithium looks likely.

If prices fall sufficiently there is no technical reason why Lithium Ion batteries should not be used for a longer duration possibly even several days.

Batteries in general are not suited for backing up renewables when generation is low for an indefinite period. Biogas or Synthetic methane produced from hydrogen offer the possibility of long term storage and the ability to drive backup generators when needed. Are these backup generators modified redundant gas peaking plant?