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# Long Duration Energy Storage: Opportunities, Challenges and Solutions – Part I

***By Harry K. Brunt****

*In this two-part article, the author considers the challenges faced by countries such as the United Kingdom that wish to reduce reliance on natural gas for heating by electrification using renewable power and the role of long duration energy storage (LDES) systems in meeting those challenges. In this first part, the author reviews the challenges for de-carbonising domestic heating and whether LDES might offer a solution. In the conclusion, to be published in the next issue of* Pratt's Energy Law Report*, the author will discuss LDES technologies, the duration of storage and efficiency, concerns for investors in and lenders to LDES projects, and green hydrogen solutions for large scale energy storage.*

Long duration energy storage (LDES) refers to energy storage systems capable of holding and releasing energy for extended periods, typically at least eight to ten hours at full power. In the past, lithium-ion battery technologies had been considered to be unsuitable for LDES owing to their self-discharge behaviour, relatively high cost at larger scales and their need for frequent cycling to obtain a return on investment. However, as costs have continued to fall, lithium-ion storage is now a serious contender, at least at the lower end of storage and power output capacities, as has been demonstrated by Ofgem's September 2025 decision on 77 eligible projects[1] to be assessed for Window 1 of the UK's proposed LDES cap and floor scheme.

Other technologies that are either already applied to LDES or considered suitable include pumped hydro storage, compressed and liquid air energy storage, gravitational storage systems, flow batteries and thermal energy storage systems.

As the world shifts its reliance away from fossil fuels towards renewables, LDES is likely to become increasingly important. A study published in 2021 by the LDES Council suggests that, by 2040, LDES will need to have scaled up to around 400 times its present-day levels to 1.5-2.5 TW output capacity and 85-140 TWh energy storage capacity globally and that 10% of all electricity

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[1] 48 of the eligible projects are based on Li-ion batteries, 21 involve vanadium flow or zinc batteries and eight are other technologies (including two proposing liquid air/battery energy storage hybrids). The government's technical decision to set the minimum power output capacity for stream 1 technologies (which include proven technologies such as Li-ion batteries) at only 100 MW (to be sustained for at least eight hours) may have skewed the eligibility criteria towards battery energy storage systems (BESSs).

generated would be stored in LDES at some point. This encompasses multiple use scenarios, with the largest proportion relating to energy time-shifting, capacity provision, and transmission and distribution optimisation in bulk power systems. In economic terms, the study estimates that this corresponds to a cumulative investment of USD 1.5 trillion to USD 3 trillion and to potential value creation of USD 1.3 trillion by 2040.

This article considers the challenges faced by countries such as the United Kingdom (UK) that wish to replace reliance on natural gas for heating with renewable power and the role of LDES systems in meeting those challenges. This is, however, only one example of the challenges of balancing supply and demand. Many of the themes explored in this article will also be relevant to other countries, including strategies for incentivising investment in LDES systems.

## CHALLENGES FOR DE-CARBONISING DOMESTIC HEATING

### What Is the Challenge in Switching From Gas to Electricity for Heating?

In a nutshell, seasonal demand variation creates a potential headache, which is discussed further below.

### How Have We Managed With Gas Heating, Which Millions of UK Homeowners Have Used for Decades?

Not surprisingly, there is a large difference between summer and winter demand for gas heating. My own home used four times as much gas during the coldest three months as during the warmest three months of 2024.[2] In less well-insulated homes, the seasonal variation in consumption could be much greater.[3]

Natural gas has for decades been relatively cheap, plentiful and easy to store compressed in large volumes. Owing to its storage capacity,[4] the UK's gas supply network is able to respond to sudden and large increases in demand.

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[2] Respectively, 7,160 kWh of gas as compared with only 1,730 kWh. My total gas consumption during 2024 was 17,180 kWh. My 30 year old gas boiler is rated 75% efficient so the output energy consumed to heat my home was around 12,880 kWh, which makes it about average.

[3] Domestic UK gas consumption during the four quarters of 2020 was 122,573 GWh, 46,401 GWh, 25,924 GWh and 105,890 GWh.

[4] According to the Department for Energy Security & Net Zero as of November 2023, the UK has nine active storage facilities (30 TWh in total), together providing only one week's worth of supply at peak winter demand and the UK is a net importer of gas via interconnector pipelines and LNG cargoes. Concerns have been expressed about the UK's low levels of gas reserves as compared with storage capacities in Europe: for example, Germany has the ability to store eight times more gas than Britain.

According to Ofgem,[5] the current aggregate peak demand for gas for domestic heating in the UK is 300 GW, which is driven by boilers providing heat on demand, many of which will be running simultaneously at times of peak demand, such as in the early morning. Other published estimates of peak demand are significantly lower, e.g., 170 GW,[6] but even this lower estimate represents a vast rate of instantaneous energy delivery, particularly when compared with the UK's total de-rated electricity generation capacity of approximately 75 GW in 2023.[7]

## What Is Different About Using Electricity for Heating?

Electricity generation and supply (and electric heating) are quite different animals to gas supply and heating. Let's assume I swap my boiler for a heat pump, for which I will assume an average Coefficient of Performance[8] (COP) of 3 during the winter and a COP of 4 during the summer. A rough calculation suggests I would use around 1,800 kWh of electricity to heat my home during three winter months (averaging about 20 kWh per day) and about 325 kWh during three summer months (less than 4 kWh per day, mainly for heating hot water), with a total additional annual electricity consumption of around 3,700 kWh, almost doubling my current annual electricity consumption.

For the UK as a whole, aggregate domestic electricity consumption is a little under 100 TWh.[9] Replacing all domestic gas boilers with heat pumps would, therefore, increase that total consumption to roughly 190 TWh or by around 90%,[10] much of which would fall during the winter months, as noted above. Of course, this is only a theoretical possibility and it would take three decades to achieve that level of uptake at the government's target installation rate of 600,000 heat pumps per year. Such a theoretical possibility also ignores the potential uptake of direct hydrogen heating using new boiler technology (on which no decision has yet been made by the government), limited blending of

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[5] Future Insights Series: The Decarbonisation of Heat.

[6] Watson, Lomas and Buswell – Decarbonising domestic heating: what is the peak GB demand? Energy Policy, Volume 126, March 2019.

[7] According to the Digest of UK Energy Statistics 2024, this includes 40.5 GW of fossil fuel capacity and 25.6 GW of renewable capacity (the remainder being nuclear and other fuels).

[8] A ratio of heat power output to electrical power input. A value of three means the heat output is three times the electrical energy consumed by the heat pump, i.e., it is 300% efficient.

[9] Statista.

[10] According to the Office for National Statistics, around 320,000 GWh (320 TWh) of natural gas is used per annum for domestic heating. Assuming an average boiler efficiency of 80% suggests total UK domestic heat demand of about 250 TWh per annum – or about 20 million homes with an average domestic heating demand of roughly 12,000 kWh per annum. 250 TWh of heat output equates to 83 TWh of electricity input, assuming an average COP of 3.

hydrogen into natural gas supplies or indeed synthesising methane from green hydrogen to replace natural gas, all of which could provide alternative methods of seasonally storing energy in the form of gas reservoirs.

If a large number of UK domestic premises currently using gas were to switch to using electrical heating, one can immediately see that large and sustained seasonal peaks in electrical power demand would arise,[11] and that demand might not necessarily be spread evenly throughout the day.

In considering the likely peak consumption of electricity, one cannot, however, simply convert the peak gas consumption to the equivalent electrical consumption (taking into account the relative efficiency of boilers and heat pumps), because heat pumps operate in a different manner to boilers, at a lower output temperature[12] and can be assumed to be less "peaky." Conventional gas boiler firing tends to take the form of on-off bursts, albeit modern boilers have the ability to modulate their burners to some extent, while heat pumps operate for longer, lower-level periods to maintain a steady temperature. In practice, therefore, instantaneous demand for electrical heating can generally be expected to be lower, and there should be a natural time averaging of demand to some extent.

If local demand-side energy storage systems were used to time-shift demand, the instantaneous demand could be reduced further. In particular, heat pump systems can be coupled with thermal storage systems (using "phase change materials," some of which can store four times as much heat energy as water for a given volume) which can be heated up at night when demand for power is lower and utilised during the day to output heat energy. Such thermal storage systems are effectively 100% efficient given that all thermal energy that is stored finds its way out directly or indirectly into the premises in which they are installed.

Another option for shifting demand would be battery storage systems, albeit these would be less efficient than thermal systems, but which offer clear benefits where solar panels are installed. Demand-based pricing might be used to

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[11] My research suggests that most UK homes can be heated by heat pumps rated between 4 and 12 kW output. If an average of 6 kW output is assumed, this would equate to around 2 kW of electricity demand per household during colder weather (when the COP might be 3 or lower). Simplistically, 2 kW x 20 million homes would represent a theoretical peak power demand of 40 GW, but only if all heat pumps were operated simultaneously, which is unlikely to apply in practice.

[12] Domestic boilers tend to have a flow temperature of 60-80°C whereas heat pumps operate at 35-55°C. Implicit in this is a lower rate of energy delivery for heat pumps and lower power consumption.

incentivise consumers to utilise such storage systems, charging them at nighttime when electricity prices are lower.

Increasing home insulation levels and using energy recovery systems (heat exchangers) in ventilation and waste water could further reduce demand by improving the energy efficiency of homes. Finally, uptake of solar panel installations, particularly when coupled with battery storage, could significantly reduce electrical demand.

Nevertheless, even if short-term peaks in demand could be smoothed out, the overall increase in demand during winter would be appreciable.[13] This seasonal peak in itself could create challenges.

## Why Is High Seasonal Peak in Electricity Consumption a Problem?

A seasonal peak in demand could cause a number of potential practical difficulties:

- In 2022, the UK's transmission network capacity was 68.5 GW and the distribution network capacity was only 35.9 GW.[14] Upgrades in network capacity might be required to support a switch from gas to electric heating, depending on the extent to which demand can be managed and smoothed over time.
- Total transmission losses in 2017 were 6,500 GWh and distribution losses 19,100 GWh. Most of the losses occur in distribution transformers and lines. Around 19% of total losses occur in distribution transformers and 28% arise in the local low voltage (LV) distribution cables and overhead lines that serve domestic and smaller commercial premises. As such, introducing large peaks in domestic electricity demand could disproportionately increase such distribution losses.
- The UK's total de-rated electrical generation capacity during 2023 was approximately 75 GW (of which 25.6 GW was from renewable sources).[15] This figure, however, does not take into account transmission and distribution and losses. Peak demand reached 58 GW during

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[13] As an arbitrary reference, my home used 160 kWh of gas on the coldest day of 2024, which would equate to about 40 kWh of electricity using a heat pump at a COP of 3. Extrapolating across 20 million homes gives a figure of 800 GWh (0.8 TWh), or approximately 1% of the total annual consumption on a single day.

[14] Statista Research.

[15] Digest of UK Energy Statistics 2024.

> 2023.[16] Current generation capacity, even when supplemented by imports of electricity via interconnectors, might be insufficient to meet the peaks in demand that would arise from widespread adoption of heat pumps, particularly after allowing for network losses, but again, the severity of the challenge may depend on the extent to which demand can be managed and smoothed.

There will, of course, be other significant factors that increase overall demand, including the uptake of electric vehicles, decarbonisation of industry and growth in data centres, but without contributing to the same extent to seasonal peaks in demand.

## Why Can We Not Simply Increase Generation Capacity to Meet Peak Demand?

Increasing generation capacity on its own to meet peak demand is unlikely to be a practical answer. Given the broad duration peak in winter heating demand, it would not make economic sense to increase generation capacity to meet the maximum projected winter electrical power demand for the coldest winter. The full additional generation capacity might only be fully used for short periods and would be underutilised for much of the year.

Moreover, renewable power is also inherently intermittent. Wind power is naturally variable and it may be difficult to predict generation capacity (winter "wind droughts"[17] occur every few years); photovoltaic power generation is absent during the night and has reduced capacity during the shorter and darker winter days as compared with the summer, which is the inverse of seasonal demand for heating. These factors are taken into account by "de-rating" assumed renewable generation capacity, but there is another side to the renewables coin: renewable power generation may, during periods of high output, result in generation capacity significantly exceeding demand, i.e., excess capacity may exist at times when it is not directly needed.

A further factor which complicates the equation of how demand can be met is the existence of interconnectors which allow importation of power from Europe and Ireland to supplement generation capacity (and the export of excess capacity). The current total interconnector capacity is approximately 10 GW.

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[16] NESO Clean Power 2030 (Annex 1: electricity demand and supply analysis), December 2024.

[17] The Germans seem to have a word for everything: dunkelflaute (dark doldrums) describes extended periods with minimal wind and sunshine that severely impact renewable energy generation.

The UK imported 33 TWh of electricity and exported 10 TWh during 2023.[18] Economics might dictate greater reliance on interconnectors rather than generation, at the expense of reduced energy security.

## LONG DURATION ENERGY STORAGE – A SOLUTION?

### What Is the Solution?

Aside from reducing energy demand through better insulation of homes[19] and managing and smoothing short-term peaks in demand via local short-duration energy storage (e.g., distributed battery energy storage systems), one answer is to store excess energy generated during periods of low demand and to use that stored energy during periods of high demand. The effect of this would be to time-shift energy generation so that the load is evened out over time. The storage must necessarily be of high capacity and long duration, potentially having to subsist over many weeks or even months.

### What Quantity of Storage Capacity Might Be Required?

Determining the appropriate capacity of LDES involves numerous variables and would be a highly complex exercise. On a basic level, the amount of storage required depends on making assumptions about future electricity demand (noting that decarbonisation will likely result in a general increase in demand)[20] and generation capacity, including both dispatchable and non-dispatchable sources, as well as the extent to which the UK may rely on interconnectors to import electricity to meet periods of excess demand.

A further uncertainty is the extent to which gas to power might continue to be utilised to meet peak demand, potentially coupled with carbon capture and storage. It also seems possible that heating networks using heat derived from nuclear and thermal power stations and other sources (e.g., large-scale disused mine heat extraction) might supplement the supply of domestic heat energy. I am not, therefore, going to attempt to guess the capacity of LDES that may be required in the future, but merely observe that it will be appreciable.

A mixture of LDES and distributed short duration thermal and battery energy storage might offer an optimised solution in combination. The reason for this is that short duration energy storage systems offer a way to spread demand over a period of hours (time-shifting intra-day), alleviating daily peaks in power demand. Not only could this reduce the peak power load on

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[18] NESO Clean Power 2030, as above.

[19] Heat pumps may be unsuitable for poorly insulated homes as their heat output may be insufficient to keep up with heat losses.

[20] There are numerous factors at play here, including electrification of road vehicles and the production of green hydrogen for decarbonising industrial processes.

generators but it could also potentially alleviate bottlenecks in distribution networks. As noted above, thermal energy storage can be directly coupled to heat pumps and offers an efficient solution to reduce intra-day peaks in demand.

## NESO's Action Plan for LDES to 2030

The UK Network Energy System Operator (NESO) projects in its Clean Power 2030 Action Plan, published in December 2024 (the 2030 Action Plan), that by 2030 electricity demand will have grown by 11% to around 65 GW (with total annual energy demand of 287 TWh) from the peak demand in 2023 of 58 GW (and total annual demand of 263 TWh).[21]

These projections involve a number of complex assumptions about growth in demand, including installation of 600,000 heat pumps per year and increases in demand driven by a five-fold growth in data centres, greater use of electric vehicles and decarbonisation of industry, as well as taking into account demand-side management (to reduce short-term peaks in demand) and improvements in energy efficiency (primarily through low energy lighting and appliances).

Currently installed LDES has a total storage capacity of only 28 GWh and power output capacity of 3 GW (mainly comprising four pumped hydro plants)[22] and additional flexible capacity has to be provided by 35 GW of unabated gas to power. Annex 1 to the 2030 Action Plan (in paragraph 3.1.2) projects that between 5 and 8 GW of LDES capacity will be needed by 2030 to manage daily and seasonal demand peaks. The 2030 Action Plan does not state the storage capacity, but one might expect it to be at least eight times the output power, given that the eligibility criteria for cap and floor support includes this assumption (see below). As such, 30 to 64 GWh of energy storage is a reasonable estimate.

The 2030 Action Plan notes that pumped hydro storage is currently the only mature LDES technology and that "new and innovative LDES technologies, such as liquid air energy storage (LAES), compressed air energy storage and iron air batteries need to be deployed, giving Great Britain an opportunity to lead the way in new technologies."

The 2030 Action Plan further suggests that hydrogen to power may require more than 1 TWh of hydrogen storage by 2030, although it is noted that Ofgem's proposed cap and floor regime (see below) does not mention hydrogen storage.

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[21] NESO Clean Power 2030 (Annex 1: electricity demand and supply analysis).

[22] Dinorwig (1983) 1.7 GW, 10.4 GWh, Foyers (1974) 300 MW, 6.4 GWh, Ffestiniog (1963) 360 MW, 7.6 GWh and Cruachan (1966) 440 MW, 7.6 GWh.

## Looking Further Ahead to 2050

NESO's 2025 Future Energy Scenarios paper sets out a longer-term view on energy storage requirements, suggesting that seasonal energy flexibility requirements will be met by a combination of bioenergy (from biomass), hydrogen to power (using hydrogen-powered turbine generators), large scale LDES and interconnectors, coupled with enabling demand-side flexibility to reduce peak demand.

The paper sets out three possible pathways to achieving net zero, as set out in Table 1, whilst a fourth "Falling Behind" scenario is presented where the pace of decarbonisation is insufficient to achieve net zero by 2050.

**Table 1**

| *Pathway to net zero* | *Description and assumptions* | *Annual electricity demand (TWh)* | *Peak electricity demand (GW)* | *Total installed generation capacity (GW)*[23] | *Energy storage output (GW)*[24] | *Energy storage capacity (GWh)*[25] |
|---|---|---|---|---|---|---|
| | 2024 values for comparison | 290 | 58 | 125 | 10 | 63 |

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[23] Includes all generation, interconnector and storage capacity as well as electric vehicle-to-grid (V2G) capacity available at winter peak.

[24] Includes V2G capacity available at winter peak.

[25] Excludes V2G storage capacity.

| | | | | | | |
|---|---|---|---|---|---|---|
| "Holistic Transition" | A mix of electrification and hydrogen, with hydrogen mainly used around industrial clusters. Hydrogen is not used for heat except as a secondary fuel for heat networks in small quantities. | 705 | 120 | 439 | 96 | 285 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Consumer engagement is very strong through adoption of energy efficiency improvements and demand shifting, with smart homes and electric vehicles providing flexibility. A high-renewable capacity pathway, with unabated gas dropping sharply. Moderate levels of nuclear capacity and lowest levels of hydrogen dispatchable power. | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Supply side flexibility is high, delivered through electricity storage and interconnectors. No unabated gas remains in 2050. | | | | | |
| "Electric Engagement" | Net zero is met mainly through electrified demand. Consumers are highly engaged in the transition through smart technologies that reduce energy demand, such as electric heat pumps and electric vehicles. | 785 | 144 | 450 | 81 | 295 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Pathway with the highest peak electricity demand, requiring high nuclear and renewable capacities. Also has the highest level of bioenergy with carbon capture and storage across all net zero pathways. Supply side flexibility is high, delivered through electricity storage, interconnectors and low carbon dispatchable power. | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| "Hydrogen Evolution" | Net zero is met through fast progress for hydrogen in industry and heat. Widespread access to a national hydrogen network is assumed. Some consumers will have hydrogen boilers, although most heat is electrified. There are low levels of consumer engagement within this pathway. Hydrogen is used for some heavy goods vehicles, | 797 | 122 | 384 | 56 | 230 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | but electric vehicle uptake is strong. Pathway sees high levels of hydrogen dispatchable power plants, leading to reduced need for renewable and nuclear capacities. Hydrogen storage provides the most flexibility in this pathway. | | | | | |

It is interesting to note that the projected annual demand values for all three scenarios are considerably greater than the prediction of 500 TWh in the 2030 Action Plan, as well as a similar estimate in the Royal Society's 2023 study.

The projected differences in energy storage capacity under each pathway reflect the extent to which hydrogen and related infrastructure is adopted. Only the Hydrogen Evolution scenario anticipates significant adoption of hydrogen for domestic heating, i.e., using hydrogen-fuelled boilers (69 TWh annual demand).

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Editor's note: This article will conclude in the next issue of *Pratt's Energy Law Report*.