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Long-duration energy storage: get on with it

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CONTENTS

EXECUTIVE SUMMARY

Long-duration energy storage technologies allow storage of energy from renewables over extended periods of time, days, weeks, or months and even years, allowing energy to be used when it is most needed. They will be essential in the future to balance energy supply and demand over time.

The Net Zero energy system will use more electricity, as fossil fuels are phased out and replaced by electricity for heating and transport. Much of this will come from renewables like wind and solar, where generation depends on the weather. Consequently, both electricity supply and demand will be much larger and more variable in the future. Whilst renewables deliver increased energy security by removing dependence on imported fossil fuels, long-duration energy storage will be needed to maintain the electricity supply, for example at times when there are prolonged periods of low wind generation. The long-duration storage replaces fossil fuels as back-up stores of energy.

Deploying long-duration energy storage technologies at scale is critical to ensure the UK can maintain energy security and reach Net Zero. They can allow more of the UK's renewable electricity to be used and help insulate the economy from energy supply shocks such as the crisis following the invasion of Ukraine.

The consequences of failing to prepare for energy supply shocks have been starkly illustrated by the recent energy crisis. In light of the huge economic damage this has caused, it is distressing to see that the Government seems to lack a clear plan for energy supply risks and indeed is still deliberating over investment in storage to prevent future crises.

Long-duration storage facilities can take 7–10 years to build and require up-front capital investment. Developers need a clear business case, supporting infrastructure such as grid connections, and financial support in order to invest. The Government has a goal to decarbonise the electricity system by 2035. If long-duration storage is to scale up in time, it is clear that construction needs to start as soon as possible. The Committee is concerned that this is not being treated with sufficient urgency.

Energy storage has multiple benefits. It allows a greater amount of cheap renewable power to be integrated into the electricity system, lowering the overall cost of electricity for consumers. It provides power capacity that can be switched on and off, making the grid more flexible. It avoids the waste when, as often occurs today, renewables have to be curtailed due to excess supply or congestion on the grid. And it provides electricity system services to the grid, such as the ability to restart after power failures. For many of these services, energy storage facilities can replace fossil fuel power plants.

If the UK establishes a strong domestic energy storage industry, it can export storage capacity and technologies. Storage would reduce the UK's dependence on costly, polluting and uncertain fossil fuel imports. Following the global mean temperature breaching 1.5°C of warming for the first full year in 2023, and as climate impacts grow, it is more critical than ever to demonstrate that a secure economy powered by low-carbon energy is possible.[1]

1 Copernicus Climate Change Service, 'Tracking breaches of the 1.5°C global warming threshold' (15 June 2023): https://climate.copernicus.eu/tracking-breaches-150c-global-warming-threshold [accessed 23 February 2024]

A number of technologies could provide long-duration energy storage, but for storage at scale over weeks and months, the front-runner is hydrogen. This can be made from water by electrolysis using excess energy generated from wind and solar, stored underground, and converted back into electricity when needed.

The Government recognises that new forms of energy storage are crucial. It is consulting on policy mechanisms to support low-carbon storage, and set a goal in the British Energy Security Strategy to deploy enough to balance the electricity system. However, key strategic decisions and policy action, not just ambition, are needed now to unlock the substantial investment required to scale up storage to the tens of terawatt hours needed. This is orders of magnitude more low-carbon storage than the UK has today.

Commercial development of long-duration storage needs financial support mechanisms for investors due to high upfront capital costs, long lead times for planning approvals and construction, and uncertain revenue streams. In addition to commercially operated storage, a strategic reserve of energy storage will be crucial for maintaining supply during rare extreme events, such as extended periods with low wind and solar generation.

The Committee was pleased to hear that the Government is consulting on a Long Duration Energy Storage business model with a cap-and-floor mechanism. This would provide revenue certainty while sharing any excess profits for commercially operated storage. However, it is unclear how much storage capacity this policy will support and it will not deliver all of the UK's long-duration storage needs.

Commercially operated storage depends on frequently buying and selling energy—there is therefore no guarantee it would be available during a crisis. This is why a strategic reserve will need to be operated under different arrangements that will ensure it is available when it is most needed.

The energy crisis that began in 2021 showed that the UK is vulnerable to global energy supply shocks. The UK spent £265 billion on energy in 2022, with £100 billion of that on oil and gas imports, compared to £159 billion in 2010.[2] The Office for Budget Responsibility estimated that Government support for energy bills alone cost £78.2 billion from 2022 to 2024.[3] The economic impact from the inflation that has been at least in part driven by energy prices is substantial and the damage has been felt throughout the UK.

The crisis provides a stark illustration of the desperate need for better energy security including domestic long-duration energy storage. It also shows that, given current economic incentives, the existing energy market will not provide it. The UK came to regret and partially reverse the closure of the Rough gas storage facility, which had shut down because the private sector argued that it was uneconomic to maintain. The Government should be planning now for how this storage capacity will be replaced.

2 Carbon Brief, 'DeBriefed' (9 February 2024): https://www.carbonbrief.org/debriefed-9-february-2024-eu-told-to-cut-emissions-90-by-2040-labours-28bn-in-context-can-northern-ireland-catch-up-on-climate/ [accessed 23 February 2024]

3 Office for Budget Responsibility, *Economic and fiscal outlook*, CP 804, March 2023, box 3.1: https://obr.uk/docs/dlm_uploads/OBR-EFO-March-2023_Web_Accessible.pdf [accessed 23 February 2024]

The Committee was very concerned to hear the Minister equivocate about whether a strategic reserve was necessary. Relying on the market to deliver energy security in a crisis will immediately pass on the costs of future energy shocks to the consumer in an uncontrolled way, as the UK has experienced recently. Failure to prepare a strategic reserve would jeopardise energy security and Net Zero.

Relying on gas as a strategic reserve would leave us again dependent on expensive, volatile imports. Cheaper, renewable energy, stored in forms such as hydrogen, offers more energy independence and security. If a reserve did use gas with carbon capture, the Government must explain how it will maintain gas infrastructure as a backup and in a way compatible with Net Zero.

The Committee welcomes the Government's reforms to the energy system, such as establishing the Future System Operator, Ofgem's new Net Zero mandate, and committing to deliver a Strategic Spatial Energy Plan that will set out in detail how the system will work and the infrastructure it will need.

But there are many actors in the energy system and it is not clear who will be responsible for delivering on this plan. Keeping everyone on the same page, cutting through red tape to deliver infrastructure at pace and ensuring the resulting energy system is coherent and resilient will need a guiding mind capable of making key strategic decisions. The Committee is not convinced that it is clear who will take responsibility for mitigating future energy supply crises.

Our report makes several key recommendations. The Government should:

- **Commit to a strategic reserve.** This will be vital for energy security. The National Infrastructure Commission recommends a strategic reserve that can generate 25 TWh of electricity a year by 2040. We are concerned that the Government seems to have only just begun thinking about whether it needs a strategic reserve and has no clear plan for supply shocks.

- **Urgently make key decisions and coordinate the delivery of an energy system plan.** The commitment to producing a Strategic Spatial Energy Plan is welcome, but there is a risk that it becomes a dead letter if the Government cannot coordinate the FSO, Ofgem, Department for Energy Security and Net Zero and public and private investment to deliver a coherent plan. Key decisions about transmission infrastructure for hydrogen and electricity must be made to allow developments to go ahead. The UK cannot wait for decisions in 2025 and 2026 to invest in storage if the commitment to a secure decarbonised electricity system by 2035 is to be realised.

- **Set an explicit minimum target for energy storage.** The Government should assess and acknowledge the likely minimum scale of storage across different durations needed to balance the energy system. This will set the scale of ambition that policies to support storage must meet. It will enable the UK to move forward now with "no-regrets" infrastructure that will be needed by 2035 regardless of how the energy system evolves. The Government cannot allow the perfect to be the enemy of the good. If it waits until it knows precisely how much storage is needed, it will be too late to build it.

- **Set out the details of its long-duration storage business model.** This should include the scale of funding that will be made available, the amount of storage the scheme will support and clarity on how it interacts with hydrogen support mechanisms. The model should support a range of technologies, not just lithium-ion batteries.

- **Support no-regrets investments for hydrogen and clarify its intended role.** A large-scale storage project that combines electrolysis, hydrogen storage and electricity generation would provide a model for other projects to follow. Hydrogen is likely to play a crucial role in strategic energy storage, so energy storage and hydrogen policy must be connected. Clarity on which applications the Government expects hydrogen will be used for would increase confidence. The UK must also secure sufficient electrolyser capacity in the face of full order books and global competition for clean technologies.

- **Act with urgency and reduce timelines.** A lack of green skills, grid connection queues and planning delays for infrastructure jeopardise any energy plan. Working backwards from the Government's 2035 commitment makes it clear that these areas need action now.

- **Engage and communicate.** The public must be engaged to ensure support for vital hydrogen and electricity infrastructure. A lack of understanding of the purpose and benefits of new infrastructure and misinformed perceptions about safety will only increase political and planning barriers.

Since 2023, the Government has had a Department for Energy Security and Net Zero. Long-duration energy storage is critical for ensuring the UK can have both: it must be a key priority for the Department. But storage needs urgent support in order to scale up in time. Major decisions about future energy infrastructure must be made and coordinated effort is needed to unlock investment in commercial energy storage and to ensure a strategic reserve is delivered.

The prize for investing in storage and decarbonising the electricity system is clear:

- cheaper, Net Zero electricity allowing the UK to combat climate change;

- a strong domestic energy storage industry; and

- an economy insulated from dependence on volatile energy markets and imported fossil fuels.

Time is running out for the UK to secure that brighter future. We urge the Government to take action now.

Long-duration energy storage: get on with it

CHAPTER 1: INTRODUCTION

1. To reach the UK's Net Zero targets, the energy system must be transformed. This involves substantial electrification—where fossil fuel use in transportation, heating and industry is replaced by electricity—in parallel with expansion and decarbonisation of the electricity supply—replacing fossil-fuelled electricity generation with low-carbon alternatives. Renewable energy, predominantly from wind and solar, is expected to play the main role in the UK.

2. Renewable energy from wind and solar will deliver a variable supply of electricity due to changes in the weather. Electrification of heating and transport means that demand for electricity will be larger and also more variable over time. Climate change and its effects on weather will also impact both renewable supply and energy demand. The electricity system will need to be substantially expanded and made more resilient to ensure that it can deliver a secure power supply whatever the load demands or weather systems it is experiencing.

3. Energy storage technologies allow energy generated by renewables to be stored over time and used when it is required and therefore are increasingly viewed as essential for Net Zero. Energy storage facilities across different durations can be used to fulfil different roles on the grid, from minute-to-minute control of the frequency and voltage of the electricity supply, through to helping to balance variations in supply and demand over hours, days, weeks or even years.

4. The Climate Change Committee (CCC) concluded that storage will play a key role in decarbonising the electricity system cheaply and effectively by the Government's 2035 target.[4] The Royal Society estimated that a substantial volume of long-duration storage, enough to supply approximately a third of current annual UK electricity generation, could ultimately be needed.[5] They found that long-duration storage is particularly important to address supply shortfalls from renewables due to infrequent but extended periods of low wind and little sunlight in winter.

5. The Government is responding to these requirements with changes to some of the key institutions responsible for planning, operating and regulating the energy system. The Department for Business, Energy and Industrial Strategy

4 Climate Change Committee, *Delivering a reliable decarbonised power system* (9 March 2023): https://www.theccc.org.uk/publication/delivering-a-reliable-decarbonised-power-system/ [accessed 10 January 2024]

5 There is a range of different estimates for the amount of long-duration energy storage needed. See box 3 for a discussion of this. The Royal Society estimated 100 terawatt-hours (TWh) of storage would be needed. See Royal Society, *Large Scale electricity storage* (September 2023), box 1: https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/Large-scale-electricity-storage-report.pdf [accessed 10 January 2024] and Department for Business, Energy and Industrial Strategy, 'Plans unveiled to decarbonise UK power system by 2035' (7 October 2021): https://www.gov.uk/government/news/plans-unveiled-to-decarbonise-uk-power-system-by-2035 [accessed 10 January 2024]

was split into new departments, including the Department for Energy Security and Net Zero (DESNZ), in February 2023.[6] The National Grid was previously split into the National Grid Electricity Transmission owners, who own the cables and substations, and the Electricity System Operator (ESO), which takes responsibility for balancing supply and demand on the grid.[7] With the introduction of the Energy Act 2023, the Electricity System Operator will become an independent body, the Future System Operator (FSO), which will take responsibility for planning the future electricity and energy systems, as well as operating them day to day.[8] The FSO is expected to be fully set up in 2024. In addition to this, Ofgem, the energy regulator, now has a specific mandate to support the Government reaching Net Zero by 2050.[9]

6. Definitions of long-duration energy storage vary—in this report we use "medium-duration energy storage" to refer to technologies best suited to storing energy between 4 and 24 hours, up to a few days at most, while "long-duration energy storage" applies to technologies that store energy across periods of multiple days, to weeks, months or even years. This report will discuss the need for medium- and long-duration energy storage and the technologies that could provide it. It will discuss existing and proposed Government policies in support of long-duration energy storage in the UK and the wider changes in the energy system required to facilitate its deployment.

7. Chapter 2 sets out the scale of long-duration energy storage needed and the benefits it can provide to the grid. Chapter 3 discusses different technologies that can provide long-duration energy storage and makes policy recommendations to support their development. Chapter 4 sets out the broader context for deploying storage in the UK energy system and makes recommendations for how it should be reformed to allow long-duration energy storage to scale up.

8. We are grateful to all who provided their views in oral or written evidence and to Professor Keith Bell, who acted as Specialist Adviser to the committee.

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6 House of Lords Library, *King's Speech 2023: Energy security and net zero* (1 November 2023): https://lordslibrary.parliament.uk/kings-speech-2023-energy-security-and-net-zero/ [accessed 10 January 2024]

7 ESO, 'What we do': https://www.nationalgrideso.com/what-we-do [accessed 10 January 2024] The electricity transmission network's wires and substations are owned and maintained by SSEN Transmission in the North of Scotland, SP Transmission in the South of Scotland and National Grid Electricity Transmission (NGET) in England and Wales. The electricity system in Great Britain is operated by the Electricity System Operator, which was split away from NGET in 2020.

8 In January 2024, it was announced that the Future System Operator will be called the National Energy System Operator (NESO). For the purposes of this report, we will refer to it as the Future System Operator as this was the name in use when our evidence was gathered. Department for Business, Energy and Industrial Strategy and Department for Energy Security and Net Zero, 'Energy Security Bill factsheet: Future System Operator' (1 September 2023): https://www.gov.uk/government/publications/energy-security-bill-factsheets/energy-security-bill-factsheet-future-system-operator [accessed 10 January 2024] and ESO, 'ESO announces the name of the forthcoming Future System Operator' (22 January 2024): https://www.nationalgrideso.com/news/eso-announces-name-forthcoming-future-system-operator [accessed 10 January 2024]

9 Ofgem: 'Ofgem welcomes Energy Act getting Royal Assent' (26 October 2023): https://www.ofgem.gov.uk/publications/ofgem-welcomes-energy-act-getting-royal-assent [accessed 10 January 2024]

CHAPTER 2: THE NEED FOR LONG-DURATION ENERGY STORAGE

The benefits of long-duration energy storage

9. Caroline Still, Senior Associate at Aurora Energy Research, outlined four needs that the grid has that energy storage could meet. The first is firm capacity, "dispatchable capacity that can provide generation during periods of peak demand". Second, flexible capacity, "the ability to generate capacity to ramp up and ramp down very quickly. As we increase the number of intermittent renewables, we will get rapid changes in generation, as well as rapid changes in demand as we electrify more of the demand." Third, resolving constraints on the network:

> "When the transmission lines are at capacity, they are unable to absorb and transmit any additional renewable energy down south, resulting in renewable turndown or curtailment [deliberate reduction in generation capacity to balance supply and demand] in the north and a turn-up of unabated thermal generation in the south to meet the demand required. Not only is this very costly to the grid—it cost about £1.6 billion in 2022—but it results in additional emissions due to the thermal generation turn-up in the south."

Fourth, grid stability and security:

> "As unabated synchronous generation is decommissioned or operated at lower load factors due to their emissions, we will see a reduction in the stability and operability of the grid. A grid that does not have security in voltage control or frequency control risks blackouts and energy security issues."[10]

Box 1: Units of energy and power, and scale of existing energy storage in the UK

For an energy storage system, the amount of energy stored, and the power—energy per unit of time—that the system can deliver at any given time are both important parameters. Together, they determine the typical timescale on which the storage system operates. Power is measured in terms of watts, while in energy the "watt-hour" is the amount of energy delivered by a one-watt power source over one hour. For example, a 40-watt lightbulb running for 25 hours would consume 1,000 watt-hours or 1 kilowatt-hour (kWh) of electricity. (These are standard scientific prefixes: kilo- means a thousand, mega- a million, giga- a billion, and tera- a trillion.) According to Ofgem, the average British household uses 2,700 kWh a year of electricity and 11,500 kWh of gas.

At the national, annual scale, the relevant units of power are gigawatts (GW) and those for energy are terawatt-hours (TWh). For comparison, the Sizewell B power station has a capacity of 1.2 GW and generates around 6.7 TWh in a typical year (as it is not always running at full capacity—the effective percentage of full capacity that is generated on average over a year is called the load or capacity factor.)

10 Q 1 (Caroline Still)

Currently, use of dispatchable fossil fuels such as natural gas is increased when demand is high and supply is low and these fuels act as a form of stored energy. The UK stores around 10 TWh of natural gas, compared to 217 TWh in Germany, 122 TWh in France, and 162 TWh in Italy.[11]

The UK currently has a relatively small amount of low-carbon energy storage deployed, mostly in the form of pumped-storage hydroelectricity (see box 2 for explanations of different forms of energy storage) at 2.8 GW of pumped-hydro, with a storage capacity of 26.7 GWh. In 2022, 2.6 TWh of electricity was used to pump water uphill in these storage facilities, which then generated 2 TWh of electricity in 2022.[12] There is also a growing capacity of battery electricity storage at grid-scale, which is discharged more frequently, usually across minutes to hours, and has been estimated at 2.4 GW (2.6 GWh) of capacity across 161 sites.

Comparing power capacity only, and not the length of time the power can be supplied for (which depends on the total energy stored), can be misleading. From these figures, if all the UK's grid-scale batteries were fully charged and discharged at once, they could provide 2.4 GW for just over an hour; if the UK's pumped-hydro was fully charged and discharged, it could provide 2.8 GW over nearly ten hours. Balancing the energy system requires matching the instantaneous power demand (GW) and also meeting the energy demand over time (GWh).

Source: Power Technology, 'Power plant profile: Sizewell B, UK' (3 February 2024): https://www.power-technology.com/data-insights/power-plant-profile-sizewell-b-uk/?cf-view [accessed 10 January]. British Gas, 'What is the average energy bill in Great Britain': https://www.britishgas.co.uk/energy/guides/average-bill.html [accessed 10 January]. Department for Energy Security and Net Zero, Digest of UK Energy Statistics Annual data for UK, 2022 (27 July 2023): https://assets.publishing.service.gov.uk/media/64c23a300c8b960013d1b05e/DUKES_2023_Chapter_5.pdf [accessed 10 January]. Royal Society, Large Scale electricity storage (September 2023), para 5.51: https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/Large-scale-electricity-storage-report.pdf [accessed 10 January 2024]. Solar Power Portal, 'Record 800MWh of utility-scale storage added in 2022' (2 February 2023): https://www.solarpowerportal.co.uk/record_800mwh_of_utility_scale_storage_added_in_2022_according_to_solar_med/ [accessed 10 January] and National statistics, 'Digest of UK Energy Statistics (DUKES): electricity' (27 July 2023): https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes [accessed 10 January 2024]

10. Energy storage capacity can allow energy to be bought at times when its availability is high and its price is low and stored until high price periods when it can be used. Martin Scargill, Managing Director at Centrica Storage, referred to an independent study commissioned by Centrica that concluded that "if we had had an extra 35 [TWh] of gas storage on the system, it would have reduced wholesale energy prices by £2.4 billion over the winter of 2021–22".[13] Energy support policies across 2022–23 were estimated to have cost over £50 billion by the Office of Budget Responsibility.[14] The Rough gas storage facility, owned by Centrica, stored 41 TWh of natural gas at its peak capacity, representing 70% of UK storage.[15] It was closed in 2017 but partially reopened in 2022 in the midst of the gas crisis—the UK has

11 Energy Monitor, 'While EU and US act, UK is unprepared for winter energy crisis': https://www.energymonitor.ai/sectors/opinion-while-eu-and-us-act-uk-is-unprepared-for-winter-energy-crisis/ [accessed 10 January 2024]

12 The 26.7 GWh of pumped-hydro capacity was charged and discharged multiple times over the year, and there are efficiency losses at each stage of the conversion.

13 Q 60 (Martin Scargill)

14 Office for Budget Responsibility, 'The cost of the Government's energy support policies' (October 2023): https://obr.uk/box/the-cost-of-the-governments-energy-support-policies/ [accessed 10 January 2024]

15 Competition and Markets Authority, *Rough gas storage undertakings review–Final report* (22 April 2016): https://assets.publishing.service.gov.uk/media/571a2323e5274a201400000f/Rough_gas_storage_undertakings_review_final_report.pdf [accessed 10 January 2024]

less gas storage than comparator nations in Europe.[16] Mr Scargill explained the economic reasons for the period of closure: "There are times when the merchant revenue of trading gas in the open market is sufficient, but it is very volatile … the costs for running or just keeping the facility open would not have been covered by the market."[17]

11. **Energy storage can provide benefits to the grid. It can reduce curtailment and grid congestion, avoiding wasting energy and reducing the cost of renewable electricity. Energy storage facilities provide power that can be turned on and off at will, enhancing grid flexibility. Long-duration energy storage therefore reduces costs elsewhere in the system and allows a greater proportion of cheap renewables to be built and so reduces electricity prices overall.**

12. **Domestic energy storage is not just about a resilient decarbonised grid—it is about the security and stability of the whole economy. The global energy crisis that began in 2021 has been an object lesson in the UK's vulnerability to global wholesale energy price fluctuations, and the consequent effects on inflation. The UK had less storage capacity than comparator nations and came to regret and partially reverse its closure of the Rough gas storage facility.**

Box 2: Energy storage technologies

Hydrogen is the leading candidate for longer-duration energy storage over weeks and months. Low-carbon hydrogen can be produced, for example from electrolysis, where electricity is used to split water into hydrogen and oxygen (see box 5). The hydrogen can then be stored under moderate pressure, for example in underground salt caverns or converted depleted gas fields, and later burned to produce electricity or converted into gases that are easier to transport, such as ammonia.

Advantages include the relatively low cost to store large volumes of hydrogen for many months or years. Disadvantages include the low round-trip efficiency (RTE) of 30–40% for electrolysis and conversion back into electricity. (At each stage of the cycle of converting electricity into hydrogen and then burning hydrogen to produce electricity there are energy losses. The round-trip efficiency is the percentage of initial electrical energy put into the storage system that is output from storage and turned into usable electrical energy.) The combination of long storage times but with low efficiency means that hydrogen for electricity is most useful for infrequent cycling and longer-term storage compared to other technologies. A single large cavern could store 200 GWh, and the technology has been deployed at pilot scale, with different components ranging from technology readiness level (TRL) 7–9.[18]

16 Reuters, 'Centrica reopens UK's Rough gas storage site in time for winter': https://www.reuters.com/business/energy/british-gas-owner-centrica-reopens-rough-gas-storage-site-2022–10-28/ [accessed 10 January 2024] and ''Relying on luck': why does the UK have such limited gas storage?', *The Guardian* (24 September 2021): https://www.theguardian.com/business/2021/sep/24/how-uk-energy-policies-have-left-britain-exposed-to-winter-gas-price-hikes [accessed 10 January 2024]

17 Q 63 (Martin Scargill)

18 Technology readiness levels exist on a scale from 1 to 9 which allow technologies to be compared based on how close they are to widespread deployment (see Figure 2).

Batteries can be used to store electricity at grid-scale. Lithium-ion batteries are widely deployed, but typically best for applications over seconds, minutes, or 1–2 hours at most, with the largest single installation globally around 3 GWh and a high round-trip efficiency of up to 90%.[19] Alternative chemistries could store energy for longer durations—flow batteries store chemical energy using a liquid electrolyte in separated tanks. The largest existing battery today can store 400 MWh, but GWh-scale is possible. Full-cycle efficiency for these batteries can be 50–80%, with a TRL of 7–8 (i.e. large-scale pilot projects.) They are best suited for storage durations up to 100 hours. Metal anode batteries are at an earlier stage of development but could potentially store energy for up to 200 hours at an RTE of 40–70%.

Compressed air energy storage (CAES) involves storing air at high pressures, where it is stored in tanks or underground caverns and can drive turbines to generate electricity. Advanced CAES (A-CAES) attains higher efficiency by storing and re-using the heat generated during this compression process. Commercial-scale CAES has been developed (TRL8–9), especially in China. Plants can store energy for up to 6–24 hours at a round-trip efficiency of 40–70%, and single caverns could store up to 10 GWh. Liquid-air energy storage involves cooling air to create liquid nitrogen, which expands rapidly when heat is reintroduced to produce electricity. The technology is relatively mature for small systems, with an RTE of around 55% and storage for a few hours on less than GWh scale.

Pumped-hydro storage (PHS) accounts for the majority (~2.8 GW) of low-carbon LDES on the grid today. It requires pumping water uphill into a reservoir for subsequent release through turbines to generate electricity. However, it requires favourable geographical features to be cost-effective, limiting its potential in the UK. It typically stores energy for up to 15 hours at an RTE of 50–80%. Dinorwig, the largest facility in the UK, stores around 9.1 GWh (1.7 GW power capacity.) Some suggestions for novel pumped-hydro storage use fluids that are denser than water to store more energy; they are at a lower technology readiness level.

Other technologies include thermal energy storage technologies, which can store heat, for example in molten salts or phase-change materials—these are discussed in chapter 3. Mechanical forms of energy storage, such as raising and dropping heavy weights on rails or in mine shafts, have also been suggested—these could store energy for several hours at a relatively small scale, but are likely to be expensive. Flywheels, which similarly store energy in rotating wheels, can be used to provide short bursts of backup power and other grid ancillary services.

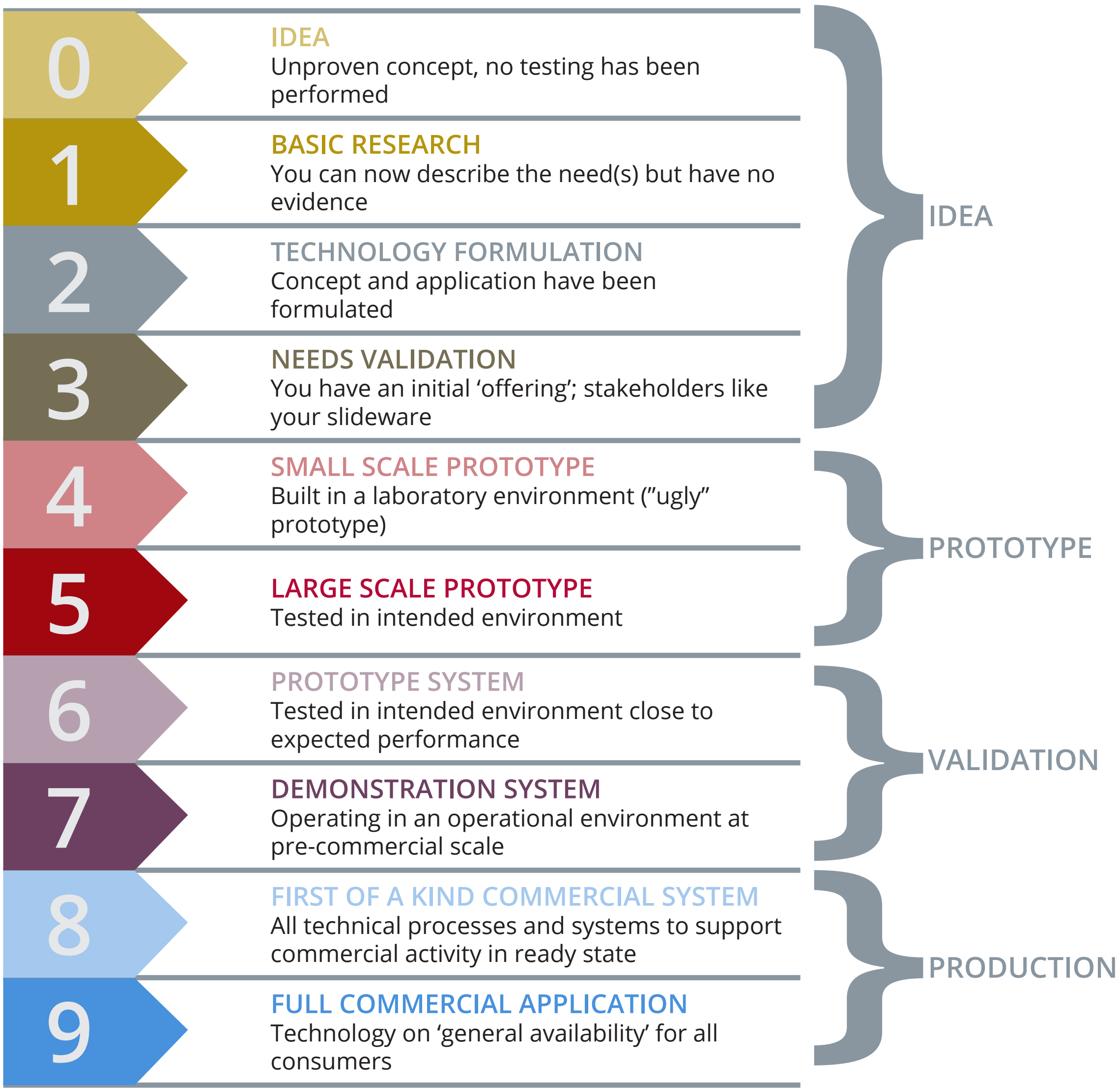
Finally, synthetic fuels—which could be produced as part of carbon capture, utilisation and storage (CCUS)—could be produced in low-carbon ways and stored in reserve as fossil fuels currently are and converted back into electricity with an RTE of around 30%. Storage on the TWh scale is possible, but these technologies are less ready (TRL 6–7) and are projected to be more expensive than hydrogen.

19 Xoserve, 'Blog: Energy storage—the missing piece of the net zero puzzle?' (7 November 2023): https://www.xoserve.com/news/blog-energy-storage-the-missing-piece-of-the-net-zero-puzzle/ [accessed 10 January 2024]

There is a general trade-off between high-efficiency but high-capital cost technologies that therefore need to cycle energy every few hours or more frequently to recover their cost (e.g. CAES, pumped-hydro storage) and low-efficiency but lower-cost storage which can store large volumes for days and weeks (hydrogen), with some larger flow batteries intermediate between these.

Source: Parliamentary Office of Science and Technology, Longer duration energy storage, POSTnote 688, December 2022. Lond Duration Energy Storage Council, Net-zero power—Long duration energy storage for a renewable grid (November 2021): ldescouncil.com/assets/pdf/LDES-brochure-F3-HighRes.pdf [accessed 27 February 2024] and Royal Society, Large-scale electricity storage (September 2023), table 4: https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/Large-scale-electricity-storage-report.pdf [accessed 27 February 2024]

Figure 1: Technology Readiness Levels Source: Technology Readiness Levels, as adapted by the CloudWATCH2



Source: CloudWATCH2, 'A brief refresher on Technology Readiness Levels (TRL)': https://web.archive.org/web/20200126083540/https://www.cloudwatchhub.eu/exploitation/brief-refresher-technology-readiness-levels-trl [accessed 19 January 2024]

13. A number of witnesses also told us that there may be an opportunity to export hydrogen and energy storage capacity.[20] As Michael Liebreich,

20 Q 11 (Professor Sir Peter Bruce) and Q 27 (Timothy Armitage)

Chair and CEO of Liebreich Associates, put it: "Germany has salt caverns … but not everyone does. In a world where everybody needs long-duration storage, perhaps we should be … leaning into it".[21] Officials recognised this potential, with Stef Murphy, Co-Director of Hydrogen and Industrial Carbon Capture at DESNZ, telling us that the Government is "clear that there is the potential for the UK to take advantage of the growth of the hydrogen economy both in the UK and globally, seizing on opportunities presented by the UK's geology, geography and infrastructure expertise."[22] However, Dr David Joffe, then Head of Net Zero at the Climate Change Committee, sounded a note of caution, telling us that "the industrial benefit of being able to export things is clearly there … but this is quite speculative at this point. It is important to recognise those opportunities, but we cannot be too definitive."[23]

14. **The UK is currently a net importer of gas for heating and power. With storage, it can develop sufficient offshore renewable generation to be more energy self-sufficient and better insulated from future global shocks. The UK could export its hydrogen and sell its energy storage capacity and expertise internationally if it develops a leading position.**

Scale and nature of the need for long-duration energy storage

15. As the UK decarbonises, it will need to electrify its energy system. Electricity demand and supply will increase substantially, with variable renewables like wind and solar playing a dominant role and increasing the weather-dependency of supply.[24] Caroline Still said that storage could be relevant across "three different demand profiles: daily, weekly and seasonal", and that variations in demand would "become more extreme" due to "electrification of things like heating and transport."[25]

16. Most energy system modellers see a significant role for a much larger energy storage capacity than exists today. Daniel Murrant, Networks and Energy Storage Practice Manager at the Energy Systems Catapult, said that "we are very much talking about tens of terawatt hours." He noted that the estimate "depends on the mix of generation technologies" (see box 2), but "whether it is 20 or 100 [TWh] … does not really matter", as at the moment we have "fractions of a terawatt hour"; a "rapid acceleration in deployment" for long-duration energy storage is required.[26]

17. Dr Joffe agreed, saying "10 terawatt hours would be pretty low-regrets in terms of what we ultimately need".[27] The Minister from the Department for Energy Security and Net Zero, the Rt Hon Graham Stuart MP, told us that: "the modelling suggests that Great Britain will need more interday and interseasonal storage in the order of terawatt hours to tens of terawatt hours to avoid a reliance on unabated natural gas" and that there was "up to

21 Q 72 (Michael Liebreich)
22 Q 89 (Stef Murphy)
23 Q 107 (Dr David Joffe)
24 Climate Change Committee, *Delivering a reliable decarbonised power system* (9 March 2023): https://www.theccc.org.uk/publication/delivering-a-reliable-decarbonised-power-system/ [accessed 10 January 2024]
25 Q 1 (Caroline Still)
26 Q 2 (Daniel Murrant)
27 Q 107 (Dr David Joffe)

£24 billion in system benefits" from having longer-duration energy storage available.[28]

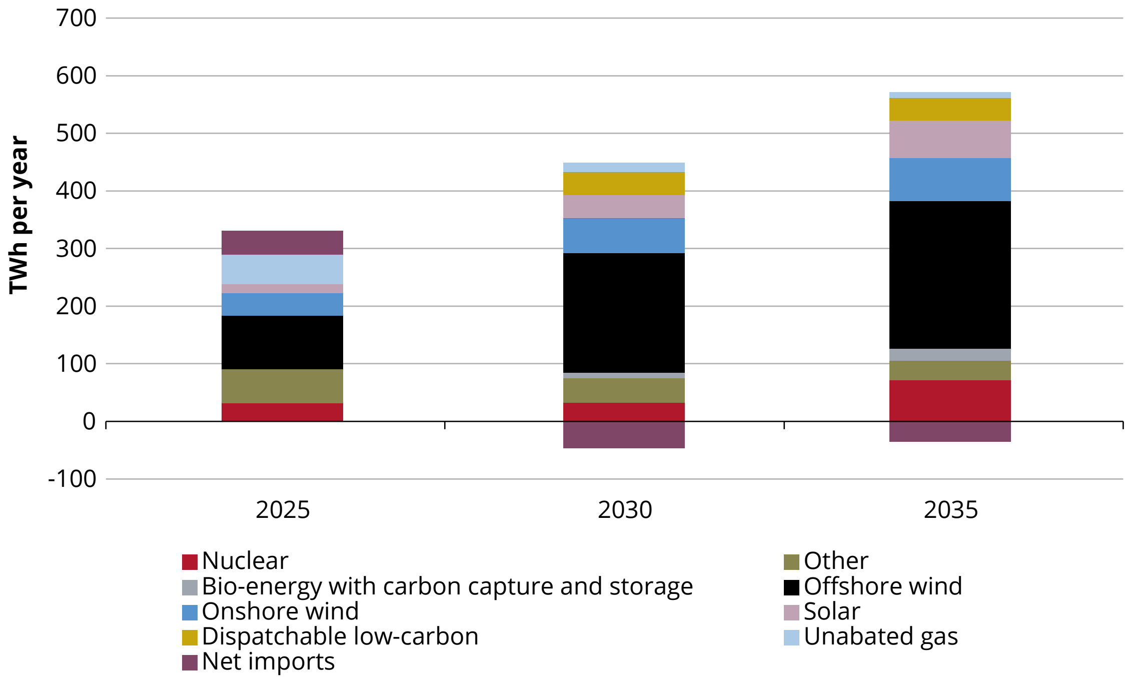
18. Asked about the potential for nuclear power, carbon capture and storage, demand-side management or interconnectors to reduce the amount of storage needed, Mr Murrant said "you can reduce it, but I do not think you can move away from that large number … however you cut it, storage is very important."[29] Mr Liebreich described the value of long-duration storage for electricity production in rare events, noting that "what you will not do for that 2% or 3% is carbon capture and storage, because that is a huge amount of infrastructure to build for use just 2% or 3% of the time."[30]

19. Ms Still said that "any sort of flexible nuclear is not proven at scale … it does not replace the role that long-duration storage plays".[31] Professor Sir Peter Bruce, Physical Secretary and Vice-President at the Royal Society, explained that "The cost of hydrogen storage would have to be at the very top of our estimates, and the cost of nuclear would have to be at the very lowest of the estimates before the two started to overlap."[32] Mr Liebreich also raised an economic objection to using nuclear to replace storage: "It does not function as back-up for wind and solar—you cannot just turn nuclear on when it is not windy—you must run it as close to 24/7 as you can, because the costs are bad enough anyway."[33]

20. Interconnectors to other countries were described as "very important" but Mr Murrant explained that "European weather cycles are broadly similar to ours", meaning that periods of high demand and low renewable supply will be correlated across Europe. Professor Bruce agreed: "our neighbours will be in a similar position; they will not have that excess generating capacity to supply to us … if we are all suffering from a shortage of electricity, I very much doubt that they will give it to us, no matter what agreements are in place."[34]

28 Q 109 (Graham Stuart MP)
29 Q 3 (Daniel Murrant)
30 Q 72 (Michael Liebreich)
31 Q 3 (Caroline Still)
32 Q 12 (Professor Sir Peter Bruce)
33 Q 69 (Michael Liebreich)
34 Q 3 (Daniel Murrant) and Q 11 (Professor Sir Peter Bruce)

Figure 2: Change in annual electricity generation under the Committee on Climate Change/AFRY's central scenario for a fully decarbonised grid.



The graph shows that there is 39 TWh in total of "dispatchable low-carbon" generation needed to balance the system in 2035, much of which will be provided by energy storage.
Source: Climate Change Committee, Delivering a reliable decarbonised power system (9 March 2023): https://www.theccc.org.uk/wp-content/uploads/2023/03/Delivering-a-reliable-decarbonised-power-system.pdf [accessed 10 January 2024].

Box 3: Estimates for the scale of need and costs for long-duration energy storage

Energy system modellers often develop a range of scenarios to cover possible outcomes, in terms of policy decisions about the energy system, technology mixes used and possible trajectories for the economy.

Different modellers will make different assumptions about the forecast mix of supply and demand, including the roles of nuclear power, gas or biomass with carbon capture and storage (CCS), interconnectors and demand-side management, for example. Both supply and demand also increasingly depend on weather conditions, which in turn are subject to climate change. The range of assumptions and constraints that are used in the model lead to a range of different estimates for longer-duration energy storage (LDES) requirements.[35] Modellers also typically try to minimise the overall cost of the energy system, subject to constraints such as reaching Net Zero targets and uninterrupted supply. This introduces a dependence on estimates for the future costs of different technologies.

35 An example can be found in box 2.1 of the CCC's Report which outlines the modelling assumptions that went into their estimates for the need for flexibility. Climate Change Committee, *Delivering a reliable decarbonised power system*, p 47

Modellers agree that electricity demand, and supply from renewables, will substantially increase as the economy electrifies to reach Net Zero. For example, the Climate Change Committee forecasts electricity demand to increase by 50% by 2035, and to double by 2050 in its Balanced Pathway scenario. In their modelling, some assumptions on the final mix of electricity generation capacity are taken from the Government's stated ambitions for wind, solar and nuclear in its 2022 British Energy Security Strategy.[36] The CCC calculate the flexibility needs, including storage, needed to balance the grid with this mix of energy generation, assuming a typical year of weather. They find that around 40 TWh of low-carbon, dispatchable back-up generation is used in 2035, of which 30 TWh (14 GW) is hydrogen generation and 10 TWh (2 GW) is gas with carbon capture and storage (CCS). This need for long-duration energy storage is further supported by 41 GWh (11 GW) of medium- and short-term grid storage capacity provided by other technologies.[37]

The Royal Society adopted a different approach. They argued that the cheapest way to generate electricity will likely be entirely through variable renewables backed up by electricity storage. They also assumed CCS would be unacceptable due to cost and CO_2 emissions and would not play a major role in the power sector. They sought to minimise the overall cost of electricity, matching supply and demand in each of 37 years of weather, as opposed to the CCC, whose central modelling used an individual year of "typical" weather, complemented by stress tests of more extreme weather patterns. The choice to model an entirely renewable energy system, and to analyse weather over a longer period of time, which therefore included some years with anomalously low generation due to low wind speeds, partly explains why the Royal Society had a greater estimate of 100 TWh for the amount of LDES required.

The Royal Society estimated that the total cost of providing an electricity system of this kind would require substantial investment from the public and private sector. They estimated that this would entail cumulative investment by 2050 of on the order of £100 billion for energy storage, £100 billion to enlarge and strengthen the transmission grid,[38] and £210 billion for the wind and solar capacity needed. For comparison, the UK spent £193 billion on energy in 2022 (8.1% of GDP).[39] The UK spent £112 billion on imports of oil-based fuels and gas in 2022 alone.[40] The cost of Government support for households and businesses was approximately £78.2 billion across 2022–23 and 2023–24,[41] and in the Royal Society's analysis electricity prices would be £60/MWh in 2050 in their renewables and storage scenario, comparable to the average over the 2010s. During the energy crisis, prices were often over £200/MWh.

36 HM Government, *British Energy Security Strategy* (7 April 2022): https://assets.publishing.service.gov.uk/media/626112c0e90e07168e3fdba3/british-energy-security-strategy-web-accessible.pdf [accessed 26 February 2024]
37 See p 54 for these estimates, which also include indicative ranges. Some of this modelling was carried out by AFRY. Climate Change Committee, *Delivering a reliable decarbonised power system*
38 This estimate is from the National Grid's calculations for a decarbonised electricity system.
39 CarbonBrief, 'Analysis: Why UK energy bills are soaring to record highs—and how to cut them' (12 August 2022): https://www.carbonbrief.org/analysis-why-uk-energy-bills-are-soaring-to-record-highs-and-how-to-cut-them/ [accessed 10 January 2024]
40 OEUK, 'UK energy import bills more than doubled to £117 billion in 2022 and could hit similar highs this year, a new Offshore Energies UK report will warn' (22 March 2023): https://oeuk.org.uk/uk-energy-import-bills-more-than-doubled-to-117-billion-in-2022-and-could-hit-similar-highs-this-year-a-new-offshore-energies-uk-report-will-warn/ [accessed 10 January 2024]
41 Office for Budget Responsibility, *Economic and fiscal outlook*, CP 804, March 2023, box 3.1: https://obr.uk/docs/dlm_uploads/OBR-EFO-March-2023_Web_Accessible.pdf [accessed 10 January 2024]

The Royal Society's estimate is an upper limit for how much storage would be required, as they model a grid with no nuclear, biomass, or gas with CCS— for energy systems with less storage, the corresponding cost of storage would be lower. Regardless of how it is delivered, the cost of nationally significant energy infrastructure is substantial—EDF estimates that the cost of Hinkley C, for example, could be as high as £48 billion.[42]

Neither model explicitly accounts for the effects of climate change on electricity supply and demand, but both include contingencies to account for this and other factors in the storage estimate. Both the CCC and the Royal Society give ranges for their LDES requirements in their reports and make arguments for the validity of their assumptions. For the purposes of this report, we do not rely on any one estimate, but note that the scale is tens of terawatts hours of long-duration storage in both of these recent, sophisticated modelling efforts to answer this question for the UK.

Sources: Climate Change Committee, Delivering a reliable decarbonised power system and Royal Society, Large Scale electricity storage

21. Despite the consensus that at least 10 TWh of storage will ultimately be needed, the Department for Energy Security and Net Zero has not set an explicit target. Emily Bourne, Director of Energy Systems and Networks, DESNZ, said that this is "one of the questions we will consider. But, at the moment, we do not have a … 'no-regrets' level."[43] She set out how they were actively consulting on whether a target would be helpful, noting that the Government had not set one at present "because of the level of uncertainty about how the system will evolve and the risk of setting a target that turns out to be inappropriate, either too high or too low."[44]

22. When asked about the specific role of long-duration energy storage in responding to a generation shortfall, the Minister said "it is hard for me to give too definitive an answer" because "there are very large terawatt hour variations between the various modelling expectations."[45] The Government set out in its Smart Systems and Flexibility Plan 2021 a target of "30 GW of low-carbon flexible assets (storage, demand-side response and interconnection)" by 2030 (and 60 GW by 2050) to decarbonise the energy system effectively, but does not state how much of this capacity is storage or give an estimate for the volume of energy in TWh that needs to be stored.[46]

23. **A fully decarbonised electricity system will need substantial energy storage across a range of timescales due to increasing variability of supply and demand in an electrified, renewable-powered economy. Estimates of how much long-duration energy storage will be needed differ depending on assumptions about future energy mix, demand, future climate and desired resilience. These assumptions affect, but do not eliminate, the need for long-duration energy storage.**

42 BBC News, 'Hinkley C: UK nuclear plant price tag could rocket by a third' (23 January 2024): https://www.bbc.co.uk/news/business-68073279 [accessed 10 January 2024]
43 Q 86 (Emily Bourne)
44 Q110 (Emily Bourne)
45 Q108 (Graham Stuart MP)
46 Department for Business, Energy and Industrial Strategy, *Transitioning to a net zero energy system: Smart Systems and Flexibility Plan 2021* (July 2021): https://assets.publishing.service.gov.uk/media/60f575cd8fa8f50c7f08aecd/smart-systems-and-flexibility-plan-2021.pdf [accessed 10 January 2024]

24. **However, there is a consensus that tens of terawatt-hours of long-duration electricity storage will be needed to decarbonise the grid, but the Government has not committed to an explicit target. This is several orders of magnitude more low-carbon storage than the UK currently has and will require different technologies from those currently used, such as the 10 TWh of natural gas storage, to be compatible with Net Zero.**

25. ***The Government should, as a matter of urgency, set an explicit minimum target for how much "no-regrets" long-duration energy storage and generating capacity it wants to see operational by 2035. It should set out a credible timescale with interim milestones for achieving this that works backwards from 2035, accounting for decision time, planning and consenting, and construction of facilities. It should also expand on the 30 GW target of short-term storage, interconnection and demand-side response set out in the Smart Systems and Flexibility Plan by outlining the minimum contribution to flexibility that each technology should make.***

26. **For energy storage systems, energy stored, typical storage duration, final output electrical energy, and the instantaneous power that can be delivered are important parameters.** ***Government policies and targets relating to energy storage—such as the 10 GW hydrogen production target—should make clear both the power (GW) and the energy (TWh) it is intended to produce and store.***

27. Energy storage can be used for many different roles on the electricity grid. As well as storage of electricity across different durations, Caroline Still outlined that older generators use the rotation of the generator to help in "voltage control [and] frequency control". As these generators are decommissioned there would be "a reduction in the stability and operability of the grid" unless the energy system services they provide are replaced. She said that "long-duration storage technologies can provide some, if not many, of those different ancillary services … [such as] inertia, reactive power, frequency control, and black start."[47]

28. Daniel Murrant told us that for "lithium-ion [batteries] … you are typically talking about a duration of two to four hours", and that even adding up millions of car batteries would "only just [get] into the gigawatt range", so

47 Q 1 (Caroline Still) Inertia in power systems is currently provided by rotating turbines in thermal electricity generators. If there is a sudden change in system frequency, such as would be caused by a power plant outage, the turbines keep spinning due to their inertia, which slows down the change in frequency of electricity on the grid while stability is restored, so it is important for controlling the frequency of the alternating electrical current. Renewables do not have the same property of spinning turbines that rotate in sync with the electricity frequency. However, any store of energy that can be accessed sufficiently quickly can help manage system frequency. See ESO, 'What is inertia': https://www.nationalgrideso.com/electricity-explained/how-do-we-balance-grid/what-inertia [accessed 10 January 2024]. Reactive power services allow the grid to maintain safe voltages (the voltage determines the amount of power transferred by a given current of electricity), and generators or other electricity system assets that can help maintain voltage control across the network are said to absorb or generate reactive power. See ESO, 'Reactive power services': https://www.nationalgrideso.com/industry-information/balancing-services/reactive-power-services [accessed 10 January 2024]. Black start is the process of restarting the grid after a partial or total shutdown, which would require isolated facilities being restarted and gradually connected to each other to form an interconnected electricity system again. This requires individual facilities in strategic locations, which are capable of switching themselves back on in case of a power outage, which the ESO can procure "black start" services from to restart the grid if needed. See National Grid, *Black start:* https://www.nationalgrideso.com/document/92386/download [accessed 10 January 2024]

the role for lithium-ion batteries would be "largely on the shorter-duration energy storage side."[48] However, he noted from his work "with SMEs in the storage and flexibility space" that "one of the key barriers is that there is still too much focus on lithium-ion", with markets "almost subconsciously set-up for lithium-ion"; he argued that "a better definition of storage" which made the distinction between "short, medium, and long-duration" would help to encourage the range of technologies that are needed.[49]

29. Caroline Still explained that a "mechanism that could benefit long-duration … storage would be one that better incentivises the additional services that long-duration energy storage can provide to the grid … in a longer-term certain price forecast."[50]

30. Professor Paul Monks, Chief Scientific Advisor to DESNZ, said "Our modelling agrees with that of the CCC, the National Infrastructure Commission and the Royal Society that we will need more interday and interseasonal storage. It will be in the order of terawatt hours to tens of terawatt hours" and he highlighted the need for a range of technologies to fill different roles: "we will use a wide variety of storage technologies, from shorter-duration technologies such as lithium-ion batteries, flow batteries and the like, through to hydrogen storage, which can provide interannual duration and provide a sustained response when deployed."[51] This distinction between storage durations may not be apparent with a definition of long-duration energy storage as anything over six hours, as proposed by the Government's consultation.[52]

31. **A range of energy storage technologies will be needed for different energy system services. We are concerned that the excessive policy and investment focus on lithium-ion storage projects has left policymakers, investors and regulators less able to appreciate the need for longer-duration technologies. There is a clear distinction between technologies which perform best across hours and for daily variations ("medium-duration energy storage"), and technologies which can store energy across days, weeks and months ("long-duration energy storage"), which a definition of long-duration energy storage as anything greater than six hours may not capture.**

32. ***The Government, supported by modelling from the Future System Operator, should clarify its definitions for medium- and long-duration energy storage and the roles they are expected to play. It should set or endorse a series of metrics that allow technologies to be compared according to the energy system services that they provide. It should use these to publish an Assessment of Likely Need for long-duration energy storage by the end of 2024; this should include storage timescales, energy stored and power capacity required. It should commit to supporting a range of technologies, beyond just batteries, through financial support mechanisms and research grants for less mature technologies.***

48 Q 4 (Daniel Murrant)
49 Q 5 (Daniel Murrant)
50 Q 5 (Caroline Still)
51 Q 83 (Professor Paul Monks)
52 Department for Energy Security and Net Zero, *Long duration electricity storage consultation: Designing a policy framework to enable investment in long duration electricity storage* (January 2024): https://assets.publishing.service.gov.uk/media/659bde4dd7737c000ef3351a/long-duration-electricity-storage-policy-framework-consultation.pdf [accessed 10 January 2024]

Urgency and pace of delivery

33. Daniel Murrant told us that "we are nowhere near what we need for the 2035 [electricity decarbonisation] target."[53] Rachel Hay, the Climate Change Committee's Head of Energy Supply Decarbonisation and Resilience, said that "the lead times are long … around seven to 10 years for hydrogen storage and seven to 12 years for gas pipelines. The Electricity Networks Commissioner, Nick Winser, talked about "12 to 14 years for electricity transmission".[54] He said that the National Infrastructure Commission "believe that those sorts of facilities—the pipelines that we talk about in the report and the hydrogen storage—can take of the order of 10 years to deliver. We are in 2023; the facilities are needed for 2035, so there is cause for urgency."[55]

34. Mr Winser added that "we should not make perfect the enemy of good." Given how much is missing, "starting to bring out something that is a high-level view … would help an awful lot and could be done quite quickly".[56] This was echoed by Ms Hay, who said "there is definitely a need for pace over perfection … it is not clear at any point in time what the precisely right answer is. The problem is that pursuing that precisely right answer is causing the problem." As Ms Hay put it: "We just need to make some decisions now, acknowledging that they may not be perfect. The worst decision that we can make is to … not make those decisions."[57] As Dr David Joffe noted, any government guidance would have to be iterative, with initial guidance set out by the Government translated into options by those such as the Future System Operator, with subsequent decisions regarding those options then made by the Government.[58]

35. **There are long lead-in times for delivering energy storage—typically estimated around 7–10 years for most technologies. If the Government waits until there is a clear picture of exactly how supply, demand and the energy system will evolve, it cannot possibly develop storage in time for a decarbonised grid by 2035. *The Government should focus on "pace not perfection" in delivering no-regrets projects—it is always possible to iterate on policy as uncertainties are resolved. It should bring forward its support schemes and no-regrets investments as soon as possible.***

53 Q 5 (Daniel Murrant)
54 Q 101 (Rachel Hay)
55 Q 53 (Nick Winser)
56 *Ibid.*
57 Q 101 (Rachel Hay)
58 Q 102 (Dr David Joffe)

CHAPTER 3: POLICY FOR LONG-DURATION ENERGY STORAGE

The economics of long-duration energy storage, support mechanisms and strategic reserves

36. Witnesses told us that the economics for long-duration energy storage projects can be challenging.[59] The Royal Society noted that "current GB wholesale market arrangements, in which long-term investment decisions and short-term dispatch are largely governed by a single price signal, will not be able to meet [storage] needs."[60] Simon Virley, Head of Energy and Natural Resources at KPMG, set out the challenges for LDES projects to become commercially viable, as including "long lead-in times", "high capital expenditure requirements" and "a very uncertain market arrangement". Ongoing uncertainty about the new "policy and regulatory framework" meant companies were "not yet in a position to take a final investment decision."[61]

37. Michael Liebreich said that there was "almost no investment going into" storage longer than 48 hours, and that "private companies can do all sorts of things, but they will not just go off and do it voluntarily when the returns are so variable and questionable, so long-distance". Consequently, "energy strategy" and "public policy" clarity was needed.[62] As discussed in chapter 2, Centrica closed its gas storage facility, Rough, because the costs to keep the storage facility open were not covered by the market.

38. There are some existing subsidies that energy storage providers can apply for. The Capacity Market offers all capacity providers a steady, predictable revenue stream, in exchange for which they must deliver energy at times of system stress and provide a fixed, reliable capacity.[63] Caroline Still discussed some of these, including energy system services procured by the ESO such as for reactive power. She described how they support some storage assets, noting that "the Capacity Market can make up to 25%" of the revenue for some long-duration storage assets, but that storage assets "rely most heavily on value derived from energy trading—charging and dispatching in the wholesale market and balancing mechanism."[64] However, she noted that "the merchant behaviour in energy trading is not significant enough" to support investment into long-duration storage.[65]

39. David Surplus, co-founder of B9 Energy Storage Ltd, described the economics from the perspective of a developer as constructing a "revenue stack … you have to get revenues from lots of different people at different

59 Q 37 (Matt Harper, Jim Isherwood and David Surplus)—each of the LODES competition winners made clear that current market arrangements would not support scale-up of their technologies and that the revenue stacks from combining support from existing mechanisms and the arbitrage markets they could access would not make them profitable.

60 Written evidence from Royal Society (LES0014)

61 Q 46 (Simon Virley)

62 Q 71 (Michael Liebreich)

63 NationalgridESO, 'Capacity Market Overview': https://www.emrdeliverybody.com/CM/overview.aspx [accessed 10 January 2024]

64 Q 5 (Caroline Still) The balancing mechanism refers to the auctions run by the Electricity System Operator to balance supply and demand on the GB electricity network. See ESO, 'What is the Balancing Mechanism?: https://www.nationalgrideso.com/what-we-do/electricity-national-control-centre/what-balancing-mechanism [accessed 10 January 2024]

65 Q 5 (Caroline Still)

times for different purposes … The electricity sector has ancillary services that we can offer. Capacity market payments can come our way, as well as electricity sales … we look to the other support mechanisms, both CapEx and revenue support" that would come from new financial support mechanisms, such as "contracts for difference" or "the new hydrogen storage business model" the Government has said it will introduce.[66]

40. The Government has recognised additional financial support mechanisms are needed and has pledged to introduce a "policy framework by 2024 to enable investment … with a goal of deploying sufficient storage capacity to balance the overall system."[67] It set out some parameters of a proposed cap and floor scheme in a consultation in January 2024.[68]

Box 4: Economics and subsidy mechanisms for long-duration energy storage

There is a significant, up-front capital cost to constructing most storage technologies, and subsequent operating costs. To get a return on investment, the incentive is for storage facilities to charge and discharge ("cycle") as often as they can, maximising their sales of electricity. Without subsidy, storage facilities depend on arbitrage—buying electricity at a low price during surplus and selling it on at a high price during supply shortages. This means storage facilities are incentivised to supply electricity when it is needed, but operators need to balance this against the desire to cycle frequently; storing energy for many weeks in hope of a better arbitrage opportunity may be less profitable than regularly selling electricity with a smaller arbitrage margin. Longer-duration storage is therefore less likely to be profitable, despite being necessary for the grid.

Revenue from arbitrage is difficult to predict and will fluctuate with supply and demand. For these reasons, long-duration energy storage projects can be a risky and uncertain investment, regardless of how important they are for the grid.

There are various proposed mechanisms for supporting long-duration energy storage:

- Facilities could be operated as a **regulated asset base**, as is currently being implemented for nuclear power, where electricity users pay for the construction of an asset over time through a levy that suppliers add to consumers' bills.
- **Contract for difference** mechanisms have been used to support offshore wind and involve agreeing a long-term contract with a "strike price" for electricity usually set through a competitive auction. When the storage facility sells electricity into the wholesale market, the subsidy "tops up" the sale price to match the strike price; if the sale price exceeds the strike price, the storage owner pays the difference back. The revenue per MWh thereby becomes predictable.

66 Q 37 (David Surplus)
67 Written evidence from Department for Energy Security and Net Zero (LES0015)
68 Department for Energy Security and Net Zero, *Long duration electricity storage consultation: Designing a policy framework to enable investment in long duration electricity storage* (January 2024): https://assets.publishing.service.gov.uk/media/659bde4dd7737c000ef3351a/long-duration-electricity-storage-policy-framework-consultation.pdf [accessed 10 January 2024]

- A **cap and floor** subsidy works in a similar way. An overall revenue cap and floor are agreed in a contract between the storage facility and the Government. If revenues exceed the cap, the extra is returned to the Government. If revenues are less than the floor, the Government pays the difference to the storage facility. The cap and floor mechanism limits risk by ensuring a minimum revenue, while incentivising the storage facility to operate to reach the revenue cap. This has been used to support electricity interconnectors.

It has also been suggested that a component of long-duration storage could be operated as a strategic reserve, which the Government could support through direct ownership or through contracting out the provision of specific storage capacities.

Source: Written evidence from Flow Batteries Europe (LES0019). Royal Society, Large Scale electricity storage (September 2023): https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/Large-scale-electricity-storage-report.pdf [accessed 10 January 2024] and Parliamentary Office of Science and Technology, Longer Duration Energy Storage, POSTnote 688, December 2022

41. Alex Campbell, director of Policy and Partnerships at the Long Duration Energy Storage Council, said that "a conventional CfD … is not necessarily the right way to do it".[69] Witnesses generally favoured a cap and floor mechanism. [70] Tim Lord, Head of Climate Change at HSBC, said that "A cap and floor regime, possibly combined with revisions to the capacity market to ensure availability, could potentially be successful", while saying "I do not think that [CfDs] work for long-duration energy storage … [as] the incentive to deliver at the right time is critical in a way that is not quite the case for renewables."[71]

42. Mr Campbell noted that a "further complication is that different types of technology will be better at delivering different types of services", and that financial support mechanisms should consider ways of supporting storage across different durations.[72] For contracts for difference which support renewable generation, the Government has introduced "different pots" of support that different technologies can apply for to support a range of technologies.[73] A mechanism like this to support technologies at different readiness levels was proposed by DESNZ.[74]

43. Alongside the pledge to introduce "an appropriate policy framework by the end of 2024 to enable investment",[75] the Government has published a "minded-to" position for its support for hydrogen storage and transportation,

69 Q 48 (Alex Campbell)
70 Q 91 (Emily Bourne), written evidence from The Quarry Battery Company (LES0005), Rt Hon Brian Wilson CBE (LES0008), Drax Group plc (LES0013), Association for Renewable Energy and Clean Technology (REA) (LES0021), Scottish Renewables (LES0022) and Foresight Group (LES0039). DESNZ also said it was the most favoured model by respondents to its consultation.
71 Q 48 (Tim Lord)
72 Q 48 (Alex Campbell)
73 Brodies, 'The Contracts for Difference Scheme: Proposed Pot Restructure' (22 May 2020): https://brodies.com/insights/renewable-energy/the-contracts-for-difference-scheme-proposed-pot-restructure/ [accessed 10 January 2024]
74 Department for Energy Security and Net Zero, *Long duration electricity storage consultation: Designing a policy framework to enable investment in long duration electricity storage* (January 2024): https://assets.publishing.service.gov.uk/media/659bde4dd7737c000ef3351a/long-duration-electricity-storage-policy-framework-consultation.pdf [accessed 10 January 2024]
75 Q 83 (Emily Bourne)

which is to address the "demand risk" for storage and transportation facilities with a revenue floor mechanism. [76]

44. It also published a consultation in January 2024 on introducing a separate cap and floor subsidy for LDES technologies.[77] Graham Stuart explained: "The consultation seeks views on key design parameters, including what types of storage should be eligible, contract length, allocation process and mitigation of risks, as well as how the scheme should be delivered" in terms of funding and ownership of the scheme. He said the consultation would close in March, receive a response in Summer, and then the Government aimed to "complete the design of the scheme by the end of this year, opening to applications in 2025." He further explained that the Government was "consulting on two application streams, one for mature technologies and one for more novel technologies."[78] Some of the questions left open in the consultation included the definition of long-duration energy storage (currently minded to be anything longer than 6 hours) and whether to open the scheme to "technologies … that would be eligible for multiple business model support", such as hydrogen.[79]

45. However, DESNZ officials were unwilling to set out the scale of funding associated with its subsidies, with Emily Bourne saying it is "hard to talk about scale of funding absent the model design and questions on scope, eligibility, and so on."[80] The Minister agreed with this and noted that "for the interconnector cap and floor … subsidy payments were never made" because with revenue certainty, interconnectors were able to make a profit, although he conceded "that will not necessarily be the case in this instance."[81]

46. **The economics of long-duration energy storage projects are challenging and they will require additional financial support mechanisms. Our witnesses generally favoured a cap and floor mechanism, and we are pleased to see the Government is actively consulting on introducing one. The Government has also stated that it is "minded to" provide a revenue floor for hydrogen transportation and storage but how this will interact with the proposed long-duration energy storage cap and floor subsidy is unclear. Hydrogen and electricity policies should be considered and designed together.**

47. ***The Government should, as a matter of urgency, finalise and set out the details of its business models to support commercial long-duration energy storage. We recommend that cap and floor support mechanisms are designed to support technologies that supply energy across different timescales, recognising the distinction between those that store energy for up to 24 hours and those that can store energy over days and weeks. The Government should clarify which technologies it considers to be eligible for the***

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76 Q 91 (Stef Murphy) and Department for Energy Security and Net Zero, *Hydrogen transport and storage infrastructure: minded to positions* (August 2023): https://assets.publishing.service.gov.uk/media/64ca0e6c5c2e6f0013e8d92a/hydrogen-transport-storage-minded-to-positions.pdf [accessed 10 January 2024]

77 Department for Energy Security and Net Zero, *Long duration electricity storage consultation: Designing a policy framework to enable investment in long duration electricity storage*

78 Q 115 (Graham Stuart MP)

79 Department for Energy Security and Net Zero, *Long duration electricity storage consultation: Designing a policy framework to enable investment in long duration electricity storage*

80 Q 93 (Emily Bourne)

81 Q 115 (Graham Stuart MP)

streams at different readiness levels, and whether the long-duration energy storage support mechanisms will be open to hydrogen. We recommend that hydrogen facilities intended for long-duration storage should be eligible for support and that the Government should resolve any overlaps between its policies.

48. ***The funding allocated to this business model must be sufficient to support deployment at scale, in line with its aim to balance the overall system, and the Government should outline the scale of funding that will be associated with its support schemes. We recommend that minimum targets for the overall long-duration energy storage capacity the model should support will help ensure support mechanisms are set appropriately to bring forward the necessary scale and range of projects.***

49. As discussed in box 3, the economics of storage projects, which aim to maximise their energy sales, may not align with ensuring stored energy is available to produce electricity when it is most needed—for example, keeping a large amount of energy stored and unsold in case of extended periods of low generation. Professor Sir Peter Bruce described "periods with virtually no wind" and "three consecutive years where demand would significantly outstrip the average supply" in their modelling, which looked at 37 years of weather data.[82]

50. Witnesses told us that it is not clear that markets will deliver every type of storage the grid might need. Michael Liebreich said that: "the private sector will not spontaneously decide that it needs to deliver one or two weeks' storage. It will invest in things that it can cycle frequently enough, where there is a market, such as arbitrage … or where there are capacity payments."[83] Witnesses, including Daniel Murrant, suggested that there is a "need for some kind of strategic reserve" of energy storage.[84] This could insulate the UK against energy supply shocks: David Gray CBE, former Chair of the Gas and Electricity Markets Authority, said that "Ukraine has demonstrated the need for strategic storage"[85] and the Royal Society identified one-in-thirty-year low wind events as showing a need for a strategic reserve.[86]

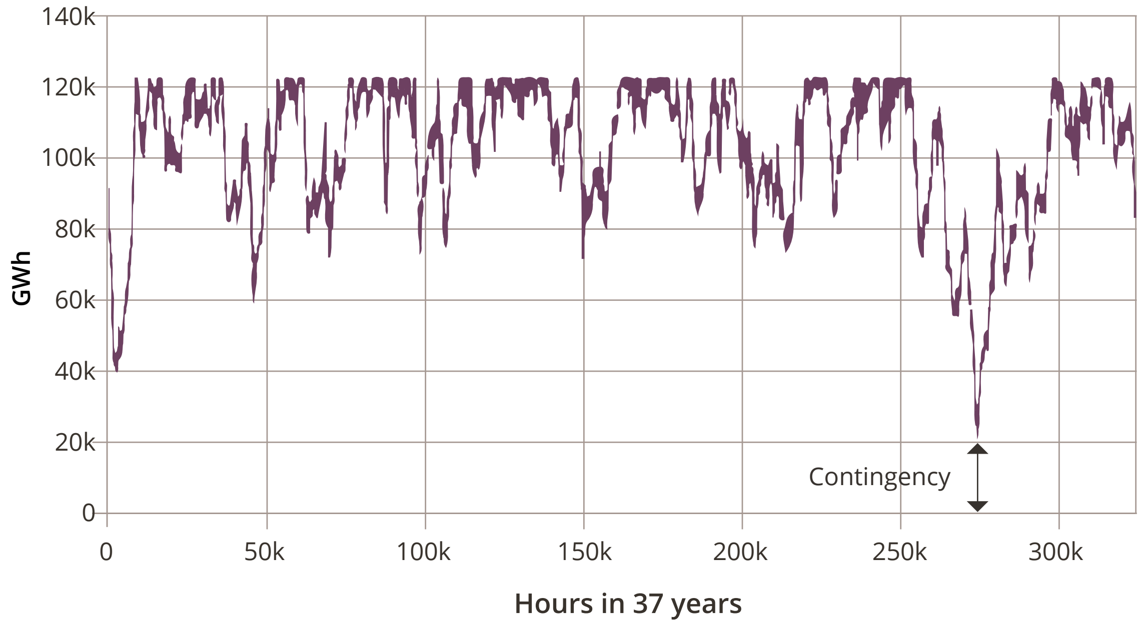
51. The National Infrastructure Commission made a specific recommendation of a strategic reserve of 25 TWh of electricity generation by 2040.[87] Nick Winser, National Infrastructure Commissioner, explained that their report proposed "a long-term, flexible generation resource using hydrogen and gas with CCS [of] 30 TWh … [or] 12 gigawatts of electricity generation", but also "a strategic energy reserve, distinct from the long-term flexibility" of 25 TWh. He suggested that by 2040 this would be "mainly by hydrogen in store" and supported by "8 TWh of hydrogen storage delivered by 2035."[88]

82 Q 9 and Q 10 (Professor Sir Peter Bruce)
83 Q 75 (Michael Liebreich)
84 Q 5 (Daniel Murrant)
85 Q 39 (David Gray CBE)
86 Royal Society, *Large Scale electricity storage* (September 2023): https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/Large-scale-electricity-storage-report.pdf [accessed 10 January 2024]
87 Strategic energy reserve in National Infrastructure Commission, *Energy and Net Zero* (December 2024), recommendation 6: https://nic.org.uk/themes/energy-netzero/#tab-headline-recommendations [accessed 10 January 2024]
88 Q 53 (Nick Winser CBE)

He explained that "you might need a different financial mechanism for securing" a strategic reserve. As the reserve will only be needed infrequently, "remunerating it on its use would not be much use"; instead it would require "a capacity-payment type of product", distinct from the "[commercial] hydrogen storage for electricity generation … under a cap-and-collar type of arrangement."[89]

52. Witnesses suggested different mechanisms to support a strategic reserve. Mr Gray said that one could "combine commercial arrangements to cover the predictable stuff with some sort of mandated requirement for the strategic element of storage", analogous to how the EU/EEA gas market now mandates winter storage.[90] Caroline Still suggested that strategic reserve capacity could be provided through a separate contracting process with storage companies: "a sort of capacity market, except one for strategic reserve."[91] Michael Liebreich suggested several options should be studied, including a "resilience levy" on electricity prices that funded Government procurement of strategic storage, "in the same way that the strategic petroleum reserve is procured."[92] He explained that "there is a role for government because it is related to security and resilience."[93]

Figure 3: Level of stored hydrogen across 37 years (Royal Society modelling)



Level of stored hydrogen in a 123 TWh store, filled by 89 GW of electrolysers, according to the Royal Society's modelling of 37 years where hydrogen storage, wind and solar provide the UK's electricity needs. This illustrates the variability of use of the store and shows that analysing weather patterns over an extended period of time substantially changes the amount of storage needed in the model.
Source: Royal Society, Large Scale electricity storage (September 2023), p 31: https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/Large-scale-electricity-storage-report.pdf *[accessed 10 January 2024].*

89 Q 58 (Nick Winser CBE)
90 Q 42 (David Gray CBE) Storage of gas is mandated by Regulation (EU) 2022/1032 of the European Parliament and of the Council of 29 June 2022 amending Regulations (EU) 2017/1938 and (EC) No 715/2009 with regard to gas storage, OJ L 173/17, 30 June 2022
91 Q 5 (Caroline Still)
92 Q 71 (Michael Liebreich)
93 *Ibid.*

53. The Government has not made a clear commitment to a strategic reserve. Stef Murphy stated that "the current business model is not designed to deliver hydrogen strategic storage reserves specifically", but that "the mechanism could be adapted to do that in future if a decision is taken that we want hydrogen to play that role."[94] Professor Monks said of options for strategic energy storage that "they have to include unabated gas" alongside low-carbon options, but was unable to set out the timing of a decision around the strategic reserve.[95] In supplementary written evidence, DESNZ said that it "acknowledged that there could be merit in exploring how a strategic reserve could be used."[96]

54. On whether a strategic reserve was needed, the Minister initially said that "the review of electricity market arrangements … is considering how we will maintain capacity adequacy in future … that includes the option of a strategic reserve." He further agreed that "under a merchant model" hydrogen might be sold in "short cycles, shorter than would be required for a national strategic reserve", necessitating "Government intervention". However, he said that "no decision has yet been made on that, but … [we] should come forward to explain whether we will have it or, if not, why we do not think that we need it."[97]

55. However, at times during his evidence, he was more sceptical, saying "We do not provide reserves on most of the things in the British economy… we look at whether there is a strategic risk that needs government intervention. Nearly always, the answer is no." He noted that "we have not created a strategic reserve for gas, even though we are terribly dependent on it", because "we produce nearly half of it ourselves and have huge LNG capacity, as well as huge imports", but concluded "if we need [a strategic reserve], we will bring one forward."[98]

56. When asked who would be responsible for responding to energy supply shocks, the Minister said that "I would expect my department or its successors to be in the lead."[99] However, he also noted that "different emergencies have different rules and different people with specific responsibility."[100]

57. **The National Infrastructure Commission has recommended a strategic reserve of 25 TWh of electricity storage by 2040. Since the economic incentive is to cycle storage often, there is a concern over how to ensure commercially operated storage is available when it is needed most. Maintaining reserve storage will likely not be profitable even with a cap and floor subsidy. The Government has not made a clear commitment to developing a strategic reserve or explained whether it thinks green hydrogen or natural gas will fulfil that role. It has not explained how it will respond to generation shortfalls without a strategic reserve, or how it will replace the storage capacity provided by Rough.**

58. ***The Government should commit to, and develop plans for, a strategic reserve of energy storage alongside commercially operated storage***

94 Q 94 (Stef Murphy)
95 Q 94 (Paul Monks)
96 Written evidence from Energy Security and Net Zero (LES0046)
97 Q 109 (Graham Stuart MP)
98 Q 116 (Graham Stuart MP)
99 Q 108 (Graham Stuart MP)
100 Q 122 (Graham Stuart MP)

on the scale suggested by the National Infrastructure Commission. This could be in the form of facilities owned and operated by the Government or strategic reserve storage capacity could be contracted out. If the Government intends to procure strategic reserve energy storage, it needs to work with industry to set out procurement terms and a scale of funding that will ensure a stable reserve and security of supply.

59. ***If unabated natural gas is to play a role, the Government must explain how this is compatible with climate change targets, in particular the Sixth Carbon budget and a decarbonised electricity system by 2035. If it will not pursue a strategic reserve, it must explain how the energy system will respond to shortfalls of renewable generation such as those highlighted by the Royal Society.***

The role of hydrogen

No-regrets investments for hydrogen

60. Witnesses generally agreed that hydrogen would play a key role in longer-duration energy storage. Daniel Murrant said that "when you get to … seasonal storage, the options become limited" and the requirement for a low-carbon gaseous fuel meant that "hydrogen appears to be the front-runner."[101]

61. The Royal Society recommended in its report on large-scale electricity storage that "construction of a large green hydrogen production and storage facility would appear to be a no-regrets option."[102] While explaining that the individual components of electrolysis, storage and conversion to electricity are "well-established technology",[103] Professor Bruce said that "I would want to build a demonstrator … to learn what we need to do when we come to scale it."[104] A single large hydrogen storage cavern would store around 200 GWh.[105]

62. Daniel Murrant told us that "one of the barriers is getting that first large-scale plant up and running"[106], while Timothy Armitage, Hydrogen Systems Consultant at Arup, said "we need demonstrator projects for depleted gas fields and for salt caverns to effectively show the perceived safety case, de-risk this investment and show that it can be scaled up."[107] The Climate Change Committee in its electricity system report urged the Government to "identify a set of low-regret electricity and hydrogen investments that can proceed now."[108]

63. Officials from DESNZ did not directly commit to supporting the construction of such a facility, although they did say that they were "keen to identify

101 Q 4 (Daniel Murrant)
102 Royal Society, *Large Scale electricity storage*, p 83
103 Q 12 (Professor Sir Peter Bruce)
104 Q 18 (Professor Sir Peter Bruce)
105 Royal Society, *Large Scale electricity storage*, p 61
106 Q 7 (Daniel Murrant)
107 Q 30 (Timothy Armitage)
108 Climate Change Committee, *Delivering a reliable decarbonate power system* (9 March 2023), chapter 2, section 3 (a): https://www.theccc.org.uk/wp-content/uploads/2023/03/Delivering-a-reliable-decarbonised-power-system.pdf [accessed 10 January]

hydrogen storage projects that will provide the most strategic value."[109] They told us that "at the moment, we do not have a 'this is the no regrets' level."[110]

64. The Minister told us that the Hydrogen Transport and Storage Networks Pathway "announced an ambition to support up to two storage projects at scale", and that the aim was that "successful projects will become operational between 2028 and 2032."[111] Stef Murphy said that they expect "our first allocation round … to be for salt caverns" and that they chose to prioritise putting the business model in place "rather than try to run pilots or pick early no-regrets projects to support." However, she was unable to set out how much storage these initial projects would provide, saying that "we want it to be at scale" but that "I do not have a figure that I can give you … we are trying to … go out to the market and see what projects are out there."[112]

65. **Although many of the components of a facility used to generate, store and convert hydrogen back into electricity are technologically mature, there are no facilities that do all three at scale in the UK. A large-scale demonstrator could help to "de-risk" investment by serving as a successful model for later projects to follow. The Committee welcomes the announcement that two projects will be supported under the hydrogen transportation and business model, but the scale of these projects is unclear.**

66. ***The Government should, as soon as possible, identify a portfolio of "no-regrets" investments into long-duration energy storage projects. This should include commissioning a pilot project that combines onsite electrolysis, hydrogen storage in salt caverns (on the scale of hundreds of GWh) and electricity generation from hydrogen. Ideally, this should be a part of, or close to, the existing hydrogen clusters. Lessons learned from this project, in terms of what is required in skills, planning and capital/operational costs should be published as the project progresses to develop policy and de-risk future projects. The Government should set out the scale of storage of the projects it intends to support with its hydrogen transportation and storage business model.***

Repurposing gas storage for hydrogen

67. We heard evidence from Centrica regarding their ambition to repurpose the Rough gas storage facility to be the world's largest hydrogen storage facility. Martin Scargill said that construction could be started "within 12–18 months" once a final decision is made.[113] As well as being in operation for 35 years as a gas facility, Rough "is adjacent to the largest industrial cluster in the UK—the east coast cluster. When you combine Humberside and Teesside's industrial emissions today, that is 50% of the UK's industrial emissions that need to decarbonise."[114]

68. Mr Scargill told us that "the upfront costs per unit storage for converting Rough could be as low as half the same amount of long-duration energy

109 Q 90 (Stef Murphy)
110 Q 86 (Stef Murphy)
111 Q 112 (Graham Stuart MP)
112 Q 113 (Stef Murphy)
113 Q 61 (Martin Scargill)
114 *Ibid.*

storage in salt caverns."[115] sked what policy action would support this repurposing, Mr Scargill said that certainty over the business model was the most important obstacle: "We see that as the main barrier to long-duration energy storage investments, given the high upfront cost and the uncertainty, particularly in the nascent hydrogen market, about where revenues will come from for such a facility."[116] DESNZ officials told us that "Centrica is certainly one of the key stakeholders that we have been talking to."[117]

69. **We heard that there could be some scope for repurposing gas storage facilities to store hydrogen in the future. This is at a lower technology readiness level than purpose-built salt caverns for storing hydrogen, which have been deployed before, but may be faster to develop.** ***The Government should work with Centrica to understand its proposed project to repurpose the Rough gas storage facility for hydrogen, with a view to determining, by the end of 2024, whether it will support this project.***

Box 5: Green, blue and grey hydrogen

Hydrogen is often labelled by the method used in its production.

- Grey hydrogen is produced by steam methane reforming (SMR), splitting natural gas (CH4)—through heating—into CO_2 and hydrogen. This releases greenhouse gases, and so must be phased out for net zero.
- Blue hydrogen production involves capturing the majority of the CO_2 that is produced in the SMR process or autothermal reforming (ATR), a combination of SMR with partial oxidation, and burying it underground, so theoretically would entail a substantial reduction in CO_2 emissions relative to grey hydrogen.
- Green hydrogen production takes a different approach, splitting water with electrolysis into hydrogen and oxygen. If the electricity used to power the electrolysers is derived from a renewable source, then green hydrogen production can be carbon neutral.

Currently almost all global hydrogen production is grey, with low-carbon production accounting for less than 1% as of 2022.[118] In net zero forecasts, hydrogen is usually produced through a mix of blue and green methods. The UK currently produces 27 TWh of hydrogen each year, 96% of which is grey hydrogen, with small pilot projects in blue and green production accounting for the rest.[119]

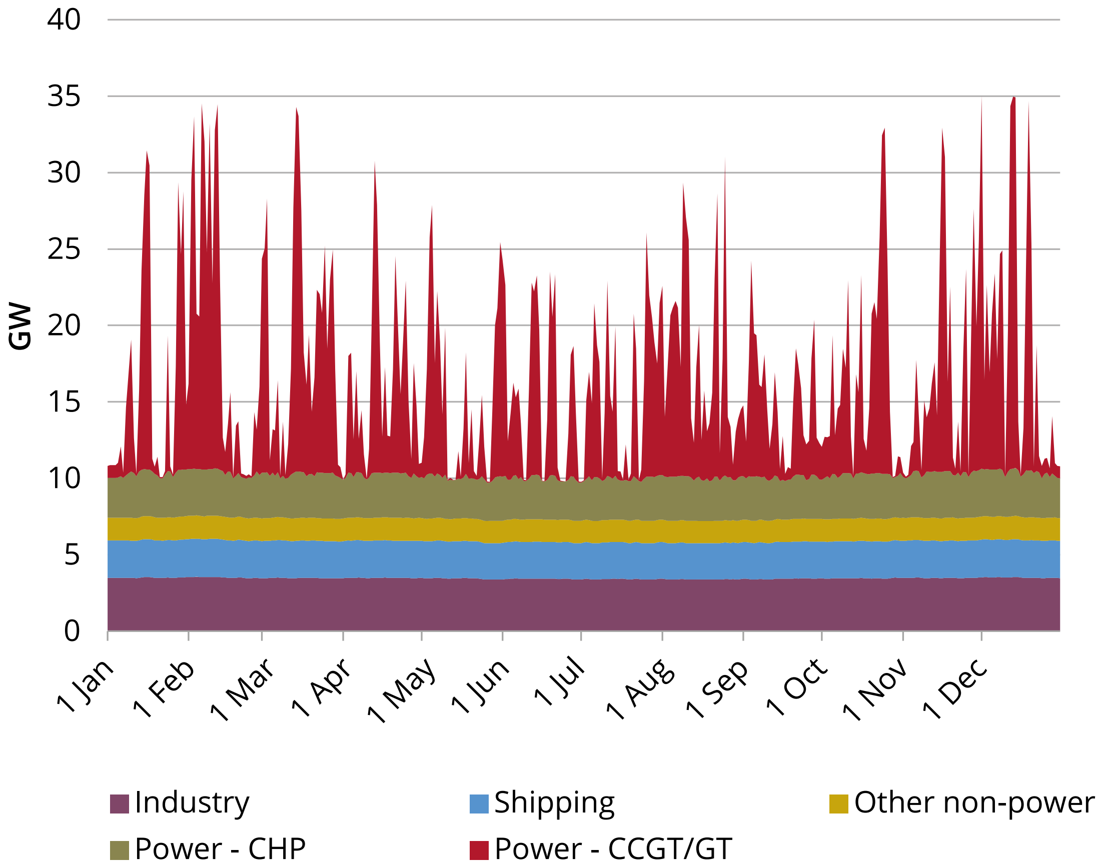
Source: National Engineering Policy Centre, The role of hydrogen in a net zero energy system (September 2022): https://raeng.org.uk/media/tkphxfwy/the-role-of-hydrogen-in-the-net-zero-energy-system.pdf [accessed 10 January 2024]

115 Q 62 (Martin Scargill)
116 Q 61 (Martin Scargill)
117 Q 90 (Stef Murphy)
118 International Energy Agency, 'Hydrogen': https://www.iea.org/energy-system/low-emission-fuels/hydrogen [accessed 10 January 2024]
119 National Engineering Policy Centre, *The role of hydrogen in a net zero energy system* (September 2022): https://raeng.org.uk/media/tkphxfwy/the-role-of-hydrogen-in-the-net-zero-energy-system.pdf [accessed 10 January 2024]

Demand and use cases for hydrogen

70. The Government has a target for 10 GW (around 64 TWh)[120] of low-carbon hydrogen production by 2030 set out in the 2022 British Energy Security Strategy, with at least half of this green hydrogen.[121] This target was described as "both stretching and credible" by Stef Murphy.[122]

Figure 4: Daily average hydrogen demand over a year in 2035 (CCC modelling)



Variation across the year in daily average hydrogen demand in 2035, according to CCC/AFRY modelling and central scenario. Note that daily average demands for hydrogen for power are volatile while requirements for industry and shipping are more steady. CHP refers to Combined Heat and Power, while CCGT/GT refers to ordinary power generation.
Source: Climate Change Committee, Delivering a reliable decarbonised power system (9 March 2023), figure 5: https://www.theccc.org.uk/wp-content/uploads/2023/03/Delivering-a-reliable-decarbonised-power-system.pdf [accessed 10 January 2024].

71. We heard that hydrogen storage projects are struggling to find private investors because of "demand risk" and "demand uncertainty"; demand

120 DESNZ explain in supplementary evidence how this figure is arrived at. It depends on assumptions such as how much of the hydrogen is blue (produced with CCS and natural gas) and green (electrolytic production.), as well as the capacity factors for the production of blue and green hydrogen. The assumption here is based on a 50/50 split between electrolytic and CCUS hydrogen, with a 95% capacity factor for blue hydrogen and a 50% capacity factor for the electrolysers, based on the assumption that they are operated flexibly. Written evidence from Department for Energy Security and Net Zero (LES0046)

121 HM Government, *British Energy Security Strategy* (April 2022): https://assets.publishing.service.gov.uk/media/626112c0e90e07168e3fdba3/british-energy-security-strategy-web-accessible.pdf [accessed 10 January 2024]

122 Q 87 (Stef Murphy)

for hydrogen is hard to forecast.[123] Michael Liebreich explained that for "hydrogen … there are still far too many uncertainties that could be shut down" in terms of what it will be used for, which would help to "focus a lot of minds and resources."[124]

72. Mr Liebreich told us that "all sorts of use cases are being proposed [for hydrogen], most of which will not happen." He set out his "hydrogen ladder" which ranked use cases for hydrogen and emphasised that priority should be given to decarbonising the "700,000 tonnes"[125] of hydrogen currently used industrially. Beyond this "there are things that are very difficult to decarbonise without hydrogen, such as aviation fuel, maybe shipping fuels, steel, and long-duration storage." However, he expressed more scepticism around hydrogen's use in heating and transport, suggesting the "use cases … will all happen in industrial hubs … [not] in homes."[126] He said that we should "rule out the use cases that do not make sense."[127] The National Infrastructure Commission also stated that hydrogen should be ruled out for domestic heating and kept for strategic energy reserve and decarbonising industry.[128]

73. Rachel Hay, Head of Energy Supply Decarbonisation and Resilience, Climate Change Committee, said that we need to "identify strategic needs [for hydrogen] … We cannot wait until 2026 for decisions on the role of hydrogen in heating."[129] Claire Dykta, Head of Markets at the Electricity System Operator, told us that delayed decisions lead to uncertainty because there would be "very different outcomes in infrastructure build … from purely a spine for hydrogen through to an extensive hydrogen ecosystem … those options need to be narrowed down".[130]

74. **We welcome the Government's ambitious target for 10 GW of clean hydrogen by 2030. However, clarity over the role of hydrogen is needed to decide on key details of storage and transportation infrastructure. Credible forecasts of demand for hydrogen would help investors to commit. We heard that decarbonising hydrogen-using industries and long-duration energy storage are good uses for low-carbon hydrogen, while domestic heating and light transport may be a distraction.**

75. ***The Government needs to clarify the role it sees for hydrogen on the future energy system assuming its target is met, with an indication of how the clean hydrogen produced in 2030 will be used. It should bring forward the decision on whether hydrogen will be used in***

123 Q 90 (Stef Murphy)
124 Q 76 (Michael Liebreich)
125 700,000 tonnes of hydrogen is approximately 23.1 TWh according to the conversion factor at Carbon Commentary, 'Some rules of thumb of the hydrogen economy': https://www.carboncommentary.com/blog/2021/6/11/some-rules-of-thumb-of-the-hydrogen-economy [accessed 10 January 2024] and Hydrogen Insight, 'Hydrogen Ladder' (23 October 2023): https://www.hydrogeninsight.com/policy/hydrogen-ladder-seven-h2-applications-relegated-in-updated-use-case-analysis-but-three-promoted/2-1-1540086 [accessed 10 January 2024]
126 Q 68 (Michael Liebreich)
127 Q 79 and Q 80 (Michael Liebreich)
128 Edie, 'National Infrastructure Commission: UK should rule out hydrogen for some heating' (18 October 2023): https://www.edie.net/national-infrastructure-commission-uk-should-rule-out-hydrogen-for-home-heating/ [accessed 10 January 2024] and National Infrastructure Commission, 'Technical annex—Hydrogen heating' (20 October 2023): https://nic.org.uk/studies-reports/national-infrastructure-assessment/second-nia/hydrogen-for-heat-annex/ [accessed 10 January 2024]
129 Q 101 (Rachel Hay)
130 Q 58 (Claire Dykta)

domestic heating from 2026—we advise against it. Hydrogen use should also be ruled out in locations and for applications that would be prohibitively expensive or without supporting infrastructure.

Availability of electrolysers for green hydrogen

76. Producing at least 5 GW of hydrogen will require substantial additional electrolyser capacity.[131] We heard from witnesses that a “key concern” was “procuring electrolysers at scale”, as there is only one manufacturer which produces a large of volume of electrolysers (around 200 MW a year) in the UK. Statera Energy, who are developing a GW-scale electrolyser project, told us that the “US’s Inflation Reduction Act and the EU’s Green Deal” subsidise their domestic electrolyser industries, making it harder for UK companies to compete. Meanwhile “manufacturers outside the UK have already sold most of their capacity for the coming years, largely to their domestic markets.”[132] Professor Bruce explained that, while electrolyser technologies can be made more efficient, “scaling up of the supply chain is the more significant challenge”.[133]

77. Stef Murphy said that the Government was “aware that developers are facing scheduling difficulties caused by lead times for electrolysers and some other key equipment, and we are working with industry on that issue.”[134] We also heard about the importance of research into more efficient types of electrolysers such as the “solid oxide electrolysis cell” which could provide a next generation technology.[135]

78. **Meeting hydrogen targets will require substantial additional electrolyser capacity, which could become a serious production bottleneck for hydrogen if not addressed. We heard that there is strong international competition for such capacity, notably from the EU and US which have significant hydrogen subsidies.** ***The Government should set out in its response to this report how it intends to obtain sufficient electrolyser capacity to meet its hydrogen production targets and ensure its approach supports domestic manufacture and research and development.***

Safety

79. We raised the issue of safety concerns with many witnesses. Industry has significant experience with using hydrogen as an industrial gas and there do not appear to be major safety concerns. Professor Bruce told us that “all energy has some safety risks, but the safety risks for hydrogen used in this sort of scenario [i.e. storage in salt caverns] are relatively small.”[136]

131 According to RenewableUK, just 4.2 MW of green hydrogen electrolyser capacity has been installed in the UK as of 2023. Around 1.4 GW of capacity is at an “early stage of development” with 69 MW under construction, approved, or in the planning system. See Renewable UK, ‘Planning system needs overhauling to enable green hydrogen projects to go ahead’ (29 March 2023): https://www.renewableuk.com/news/636005/Planning-system-needs-overhauling-to-enable-green-hydrogen-projects-to-go-ahead-.htm [accessed 10 January 2024]

132 Written evidence from Statera Energy (LES0023)

133 Q 14 (Professor Sir Peter Bruce)

134 Q 89 (Stef Murphy)

135 Q 36 (David Surplus)

136 Q 14 (Professor Sir Peter Bruce)

Martin Scargill told us that:

> "The industry needs to deal with safety regardless of where it is stored. The facilities above ground, the pipework and everything else are the same. You are just looking at certainty around the integrity of the structure. We are very confident. Salt caverns are typically built in salt strata about a kilometre down. Rough field is three kilometres down. Part of the overburden structure is an 800-metre layer of salt, so it will not leak, but we have to prove it."[137]

80. The actual degree of safety of hydrogen for long-duration energy storage has to be distinguished from the public perception of this safety.[138] As Timothy Armitage put it to us, "We cannot just say to people, 'We're going to build all of these hundreds of salt caverns under Chester' … We need to bring them on board and we need clear stakeholder engagement as part of that."[139] He suggested that one way of doing so would be with "demonstrator projects for depleted gas fields and for salt caverns to effectively show the perceived safety case".[140]

81. Nick Winser also told us that "the planning process will be eased by having much better discussion with communities, being much more open and more respectful and having much better political, economic and engineering context laid out to communities."[141]

82. When raised with DESNZ officials, they told us that they did "not know what public opinion work has been done."[142] Professor Monks said that the Government "will do hydrogen tests in given areas with the consent of the public. Public opinion and working with the public in areas are an important feature of all the parts of the energy transition".[143]

83. On public engagement, Graham Stuart said that "it is incumbent on us to get out and tell that story as much as we can … we need to do it in a way that allows us to move at the pace required and yet genuinely engages with people and listens to them."[144] However, he conceded that "I do not think I would claim that we were ahead of the curve in explaining and sharing this with everyone. Typically for a project, it is not government that goes out and does this. It is the developer that has the duty to engage … and some do that better than others."[145]

84. Both Martin Scargill and Arnaud Réveillère, Head of Green Storage, Net-Zero Solutions at Geostock, discussed the risk of microbes producing unwanted hydrogen sulphide through chemical activity when hydrogen is stored. This could result in problems such as "embrittlement" for steel and

137 Q 62 (Martin Scargill)
138 It is also important to distinguish between hydrogen stored in salt caverns and processes at industrial sites and hydrogen for heating homes: our focus is on the former.
139 Q 27 (Timothy Armitage)
140 Q 30 (Timothy Armitage)
141 Q 53 (Nick Winser)
142 Q 96 (Stef Murphy)
143 Q 96 (Professor Paul Monks)
144 Q 113 (Graham Stuart MP)
145 Q 121 (Graham Stuart MP)

would require treatment at the surface because of its toxicity.[146] Mr Scargill told us that "it is very hard to assess its impacts at industrial scale. We know that it will happen, but whether it will impact and by how much is very difficult to say."[147] Mr Réveillère agreed that it "is difficult is to assess the scale of those reactions".[148]

85. **We heard no evidence to suggest that hydrogen is unsafe, especially when used as an industrial gas. However, the public perception of safety is vital, as negative perceptions of hydrogen projects could prove to be an obstacle in the planning process. We were disappointed that the Government does not seem to recognise this distinction or its crucial role in securing public support, and the Government has work to do to explain the role of hydrogen and its safety profile to the public.**

86. ***DESNZ should commission research in the next six months into the public acceptability of hydrogen storage, in particular in the local communities which are most likely to host it. A public information and dialogue campaign that explains the envisaged role for hydrogen, as well as its safety aspects, is essential and must be a priority for the Government—it cannot be left to developers. The campaign should emphasise the importance and benefits of these energy infrastructure projects for national and economic security, as well as the industry experience with producing and using large volumes of hydrogen today.***

87. **Some uncertainties remain around some of the operating and safety parameters for hydrogen storage—for example, the potential for microbial production of hydrogen sulphide.**

88. ***The Government should work with UKRI to commission research into the safety aspects of hydrogen storage and transportation, as well as the public acceptability of hydrogen transport and storage facilities.***

Medium-duration energy storage technologies

89. As discussed in box 2, there is a wide range of energy storage technologies which can play different roles across different timescales in balancing the grid. This section focuses on technologies best suited to medium-duration storage.

Pumped-storage hydropower

90. Pumped-storage hydropower is a proven technology that currently provides the majority of medium-duration (6–24-hour) storage in the UK—however the 2.8 GW (27 GWh) of storage was "state funded over 60 years ago."[149] We received evidence from pumped-storage developers which suggested a

146 Q 67 (Arnaud Réveillère). Potential harms caused by unwanted hydrogen sulphide production are set out in Christina Hemme and Wolfgang van Berk, 'Potential risk of H2S generation and release in salt cavern gas storage' *Journal of Natural Gas Science and Engineering*, vol 47 (2017): pp 114–23: https://doi.org/10.1016/j.jngse.2017.09.007

147 Q 65 (Martin Scargill)

148 Q 67 (Arnaud Réveillère)

149 Written evidence from the British Hydropower Association (LES0038)

significant pipeline of projects remain at various stages of planning—"7.8 GW across a pipeline of 6 projects with 135 GWh of storage."[150]

91. We heard that pumped-hydro "takes about five to seven years to build",[151] but as "the capacity market allows for bids to deliver up to four years in advance", they cannot receive any subsidy under this mechanism.[152] Witnesses explained that due to "high capital costs, long lead times, and lack of revenue certainty", the policy support was insufficient for more projects to be developed without a cap and floor scheme and that "likely delays in promised policy decisions are jeopardising investment in PSH."[153]

92. **Pumped-storage hydropower could play a valuable role in partially fulfilling medium-duration storage needs. We heard from the pumped-storage hydropower industry that a pipeline of projects is at various stages of development but will require additional support mechanisms to proceed. Projects could take seven or more years to construct, so final investment decisions are urgent if they are to be ready by 2035.**

93. ***The Government should consult with the pumped-storage hydropower industry to determine the levels of the cap and floor support mechanism that might be needed to support projects that already have planning permission. Projects that can demonstrate their cost-effectiveness should be supported by the long-duration energy storage business model.***

Compressed-air energy storage

94. We heard from witnesses that CAES and ACAES can be a valuable medium-duration storage technology (200–500 MW, 6–12 hours). Jim Isherwood, Study Manager at io consulting, told us that there are "well-progressed projects … in California and in New South Wales, Australia" as well as China.[154] The Royal Society's report found that adding CAES to their storage model reduced the average cost of electricity under certain cost and efficiency assumptions: Professor Sir Peter Bruce said that "we would see it as part of the mix, particularly as part of … medium-generation … timescales of perhaps several hours.".[155] We heard that it would play a "complementary" role rather than being in competition with hydrogen;[156] Michael Liebreich explained that it is "at a higher cost point because of its complexity … if it is going to serve a role, it will have to cycle multiple times a year."[157]

95. As with other long-duration energy storage projects, witnesses expressed a clear sense of urgency. Mr Isherwood said "for us to be able to put ACAES

150 Written evidence from the British Hydropower Association (LES0038) and Scottish Renewables (LES0022) gave estimates from a range of developers. Individual projects were cited by SSE (LES0003), Quarry Battery Company Ltd (LES0005), Drax Group plc (LES0013), RheEnergise Limited (LES0025) for novel PSH, and Foresight Group LLP (LES0039)
151 Q 84 (Emily Bourne)
152 Q 41 (Ita Kettleborough)
153 Written evidence from SSE (LES0003) and Scottish Renewables (LES0022)
154 Q 32 (Jim Isherwood)
155 Royal Society, *Large Scale electricity storage*, chapter 8.4
156 Q 63 (Arnaud Réveillère)
157 Q 74 (Michael Liebreich)

facilities on the grid in time for 2035, next year [2024] would be nice to get this sorted out."[158]

96. **Advanced compressed air energy storage (ACAES) could store energy on the timescale of 4–24 hours and help to manage medium-term variations in demand. However, as a relatively new technology, cost estimates vary widely. The Royal Society found that the availability of some CAES could reduce overall costs for the energy system under some circumstances if it can cycle quickly.** ***The Government should investigate the costs and efficiencies of large ACAES, for example through researching comparable systems that have been operated in other countries, with a view to supporting them through the long-duration energy storage business model in 2024.***

Longer-duration battery chemistries

97. This report has discussed the focus on lithium-ion batteries and their potential usefulness for short-duration storage. The Committee heard evidence around other battery chemistries, such as iron air batteries.[159] Professor Pam Thomas, CEO of the Faraday Institution, highlighted "flow batteries, which go into the days to weeks element of storage", as well as "lithium-air batteries, which are still being researched. Those would be up to hundreds of hours of storage" as having a role to play in medium-duration storage.[160]

98. There is a significant pilot-scale redox flow battery project of 5 MWh in the UK at the Energy Superhub Oxford, and some flow battery companies based in the UK.[161] Matt Harper, Chief Commercial Officer of Invinity Energy Systems, described the project that had been supported "under the longer-duration energy storage programme is one where we will take a 30 megawatt hour vanadium flow battery manufactured in the UK" and provide "regulation and energy-trading services directly on to the electric grid." This project was described as being in "the development phase" with construction in 2024.[162] However, industry witnesses, such as Flow Batteries Europe, raised concerns that "the UK is lacking in manufacturing capacity" compared to countries with large-scale flow battery factories.[163]

99. Professor Thomas told us "there is no concerted programme on battery storage for the grid", although some individual research projects were highlighted. She described grid storage as "part of our remit" but there was no "hypothecated funding", as most of the funding for research comes from the automotive sector.[164] The industry has suggested that "more funding of flow battery pilots and demonstration projects is needed."[165] The Government's recently published battery strategy mentions flow battery projects that were

158 Q 38 (Jim Isherwood)
159 Written evidence from Form Energy (LES0018)
160 Q 20 (Professor Pam Thomas)
161 Q 32 (Matt Harper)
162 Q 31 (Matt Harper)
163 Written evidence from Flow Batteries Europe (LES0019)
164 Q 24 (Professor Pam Thomas)
165 Written evidence from Flow Batteries Europe (LES0019)

funded under its Long Duration Energy Storage demonstrator scheme, but does not make any new commitments specific to flow batteries.[166]

100. **Lithium-ion batteries have been a central focus of battery development in the UK because of their uses in the automotive sector, but alternative chemistries such as flow batteries or iron-air batteries will be more suitable for medium-duration grid-scale storage across multiple days. The UK has some pilot projects for flow batteries which could be expanded.**

101. ***The Government's industrial battery policy should outline a clearer role for flow batteries and iron-air batteries that might have grid-scale applications. The Faraday Institution and related battery R&D funding initiatives should be expanded to enable dedicated funding to chemistries that can be useful for grid-scale storage.***

102. ***Early-stage technologies like ACAES, flow batteries, and large-scale thermal storage would benefit from the commission of large-scale demonstration projects and the Government should consider co-funding some large-scale pilot projects with industry.***

Incentivising the right mix of technologies for the grid

103. As discussed, there was a consensus among witnesses that "we will use a wide variety of storage technologies, from shorter duration technologies such as … batteries … through to hydrogen storage" to fulfil different roles on the grid.[167]

104. Owen Bellamy, Head of Power Sector, Climate Change Committee, made a distinction between how technologies should be supported at different phases of the energy transition. There was a difference between those that are ready now and those that "are not commercially available in the marketplace" where the Government needs to "take strategic decisions about supporting these technologies, ensuring they become commercially viable". Once they are ready, then you can adopt a "technology neutral approach."[168]

105. Long-duration energy storage developers suggested that capacity markets and CfDs "do not recognise the significant … ancillary benefits" of long duration storage such as reducing curtailment and that "system requirements should be the priority focus" for policy interventions.[169] We were told that these benefits are "not recognised by Power Purchase Agreements" which are negotiated directly between electricity generators and customers. These services are instead "procured separately by National Grid ESO, in a fragmented, ad hoc and piecemeal" manner.[170] DESNZ itself told us that long-duration energy storage was limited by "a lack of forecastable revenue streams" in the current market. The Renewable Energy Association told us that a "competitive tender processes for system needs" could support a range of technologies.[171]

166 Department for Business and Trade, *UK Battery Strategy* (November 2023): https://assets.publishing.service.gov.uk/media/656ef4871104cf000dfa74f3/uk-battery-strategy.pdf [accessed 27 February 2024]
167 Q 83 (Professor Paul Monks)
168 Q 106 (Owen Bellamy)
169 Written evidence from Drax Group plc (LES0013)
170 Written evidence from the Renewable Energy Association (LES0021)
171 *Ibid.*

106. Other witnesses pointed out that "in the detail of energy systems, as soon as you specify what you need, it tends to tilt it towards one technology outcome",[172] thus ensuring that the best technologies at providing a given service are incentivised. Caroline Still explained that once you have a "[revenue] floor to de-risk debt … other mechanisms could help to provide an additional upside to attract [investment]" in the necessary technologies, such as "longer-term certain price forecast[s]" for ancillary services such as reactive power and inertia.[173]

107. Mr Bellamy told us that "the key thing is that the Government need to set out … which standards they expect to be needed in the future and to design a policy framework that enables that to be met. You would not expect the market by itself to deliver that, because security of supply is a property of everything that is happening."[174]

108. **There is agreement that a mix of technologies is likely to be needed for long-duration energy storage. Hydrogen is likely to be the best solution for storage across multiple weeks and months, but there is a range of competing technologies for storage across hours and days, which can also provide different services to the grid. Long-duration energy storage developers argue that the overall value they provide to the grid in terms of electricity system services is not yet properly incentivised, meaning the revenue stack for projects does not always add up. More information about how the Future System Operator will procure energy system services would encourage investment and healthy competition. Financial support mechanisms and market arrangements should be designed support a mix of storage technologies that provide the services the grid needs.**

109. ***The Government, supported by the Future System Operator and as part of its planning, should incentivise the right mix of technologies by specifying in detail which energy system services it wants to procure, including storage capacity and duration, in line with the Assessment of Likely Need. This should include suggested levels of payment and published modelling should project the likely levels of demand so that revenue streams can be forecast. Energy storage projects that can provide additional services to the grid should be incentivised to do so by receiving additional payments above the "revenue floor" if they are eligible for the commercial long-duration energy storage cap and floor mechanism.***

172 Q 75 (Michael Liebreich)
173 Q 5 (Caroline Still)
174 Q 106 (Owen Bellamy)

CHAPTER 4: LONG-DURATION ENERGY STORAGE IN CONTEXT

110. This chapter will include a brief discussion of some of the complementary solutions that can be deployed alongside long-duration energy storage, as well as a brief outline of the barriers to and context for its deployment, as well key actors in the energy system, and decisions that need to be made in the next 1–3 years.

Planning and regulatory systems

Connecting projects to the grid

111. The Committee heard from projects that had won funding from the Government's Longer Duration Energy Storage Demonstration (LODES) competition.[175] Alongside the commercial pathway, they identified other barriers: Jim Isherwood, from io Consulting, who worked on a LODES-winning project to develop a 100 MW advanced compressed air energy storage facility, told us "The grid connection offer for our project was November 2037."[176] We were told "there is a tremendous queue of applications, and the sheer number … has almost overwhelmed the process for National Grid."[177] Ita Kettleborough, Director at the Energy Transitions Commission, explained that "the grid processing queue was developed in a world where there might be two, three or four major thermal plants a year. Now, the ESO is receiving around 1,600 applications a year."[178] She set out that there were more than twice as many projects in the queue as the UK would actually need. David Gray stressed the importance of "a way to prioritise the queue."[179]

112. Mr Isherwood suggested that the ESO treats energy storage projects in a similar way to other energy generation projects, despite the fact that it can "alleviate constraints" and "de-bottleneck" the grid, but that appreciating this would require "a holistic view of the system."[180] Officials from DESNZ explained that reforms announced by Ofgem will allow "the system operator to insert milestones in connection agreements" and prioritise projects that are ready to connect, while terminating projects that have stalled.[181] The Committee also welcomed the recent publication of the Connection Action Plan.[182]

113. **We heard from would-be long-duration energy storage project developers that connecting to the grid is a barrier that can prove fatal**

175 Department for Energy Security and Net Zero and Department for Business, Energy and Industrial Strategy, 'Longer Duration Energy Storage Demonstration (LODES) competition (closed to applications)', 12 April 2023: https://www.gov.uk/government/collections/longer-duration-energy-storage-demonstration-lodes-competition [accessed 10 January 2024]
176 Q 34 (Jim Isherwood)
177 Q 38 (Jim Isherwood)
178 Q 43 (Ita Kettleborough)
179 Q 43 (David Gray)
180 Q 34 (Jim Isherwood)
181 Q 96 (Emily Bourne) and Ofgem, 'Ofgem announces tough new policy to clear 'zombie projects' and cut waiting time for energy grid connection' (13 November 2023): https://www.ofgem.gov.uk/publications/ofgem-announces-tough-new-policy-clear-zombie-projects-and-cut-waiting-time-energy-grid-connection [accessed 10 January 2024]
182 Department for Energy Security and Net Zero, *Connections Action Plan: Speeding up connections to the electricity network across Great Britain* (November 2023): https://assets.publishing.service.gov.uk/media/655dd873d03a8d001207fe56/connections-action-plan.pdf [accessed 10 January 2024]

to projects. The Committee welcomes the recent announcement that Ofgem is reforming the queue to remove non-viable projects, as well as the reforms proposed in the Connection Action Plan. This will be critical to ensuring a pipeline of projects can be developed in time.

114. ***Ofgem and the ESO should reduce the grid connection queue urgently and speed up timelines to connect projects to the grid. They should publish updates on how the reforms are progressing reducing the queue of proposed projects. They should consider prioritising storage projects for accessing the queue given their additional benefits such as alleviating grid constraints as well as acting as flexible generation.***

Obtaining planning permission for energy storage

115. Many witnesses highlighted the planning framework as a major obstacle to storage projects. David Gray mentioned a project developing a natural gas storage site in north-West England during which he was "absolutely staggered at the extent of local resistance for a facility that, once built, would be pretty well invisible. Essentially, it was an objection to any development on the rural landscape. That is a major blockage to most large-scale energy projects."[183] The ESO's Claire Dykta agreed, telling us that "a big blocker in any infrastructure build over the next 10 years will be the planning laws. They need to be reformed, otherwise there is a big risk to the delivery of even existing technology, never mind new technologies, by the mid-2030s."[184]

116. Mr Isherwood told us that "having to go through the Development Consent Order (DCO) route for planning applications … would be a long-winded process. It would push our development timeframe to five to seven years before we [could] take an investment decision."[185] This is against a background in which, as Martin Scargill told us, "if we just go with the Natural Infrastructure Commission recommendation of eight terawatt hours by 2035, that is as many salt caverns to be built in the next 12 years as have ever been built in the UK."[186]

117. It is not clear that the planning system is ready for Net Zero; Ita Kettleborough said that a "strategic vision" was needed for planning and permitting, especially as the current system "has been operating for the last 30 or 40 years [and] reasonably assumed a steady state, but our electricity usage in the UK has been declining, not doubling."[187] Energy UK told us that "current barriers to hydrogen storage include the lack of a licensing route for onshore hydrogen storage."[188] Ørsted told us that: "It is not clear how LDES technologies will be defined in the planning regime and whether the system and energy security benefits will be treated in the same way as renewable generation under the Nationally Significant Infrastructure Project definition."[189]

183 Q 41 (David Gray)
184 Q 55 (Claire Dykta)
185 Q 34 (Jim Isherwood). Development Consent Orders (DCO) are the means of obtaining permission to construct and maintain developments categorised as Nationally Significant Infrastructure Projects.
186 Q 62 (Martin Scargill)
187 Q 41 (Ita Kettleborough)
188 Written evidence from Energy UK (LES0040)
189 Written evidence from Ørsted (LES0006)

118. Nick Winser was more optimistic. He told us that "although people find that planning process quite difficult, it is fundamentally sound."[190] He suggested that a Strategic Spatial Energy Plan (see later in this chapter) would help "inform the Planning Inspectorate's view" of applications and ensure that a "broader political, economic, and engineering rationale" is laid out.[191] His Electricity Network Commissioner's report concluded that the current timescales for completing infrastructure projects could be halved: "it currently seems to be 14 years … We can drive it down to seven, so that would still fit into the timescales we have."[192] The Minister set out some ongoing reforms to planning, including "updated national policy statements" and reforms to the Nationally Significant Infrastructure Projects planning system.[193]

119. **We have heard that obtaining planning permission for energy storage facilities can be difficult and add significantly to timelines. It is not clear that the planning system has distinct guidance for energy storage facilities as opposed to energy generation. There currently is no regulatory licensing regime for the onshore storage of hydrogen, so developers need additional guidance from Government.**

120. ***The planning system must be reformed and sufficiently resourced to deal with the additional strain on it from new energy projects. It must recognise storage for its own value for energy system resilience by the end of 2024. The Government, working closely with Ofgem, should identify and set out the regulatory barriers to storage project developments and explain what actions it will take to address them. This should include more detailed guidance for developers on navigating the planning system, as well as clarifying how onshore storage of hydrogen will be regulated and licensed.***

Skills for net zero

121. Concern about skills gaps and skills shortages for Net Zero are widespread.[194] We heard contrasting views on the availability of the necessary skills for the Net Zero transition. For example, for battery storage projects, Professor Thomas, CEO of the Faraday Institution, told us of a blueprint for the National Electrification Skills Framework and Forum (NESFF), developed in collaboration with WMG and the High Value Manufacturing Catapult, which aims to provide "the suite of skills required from level 3 right up to level 8, so PhD skills at the top level. This framework is envisioned to extend beyond passenger automotive to encompass various transport modes as well as stationary energy storage solutions."[195]

122. David Surplus, whose company B9 Energy was awarded LODES funding to develop a hydrogen storage project, said that the disciplines needed were "the electrical power sector, the oil and gas sector, the chemical industry, and … the water industry", adding that "the skills are all there and the academic institutions are happy enough that the courses and curriculums

190 Q 57 (Nick Winser)
191 Q 59 (Nick Winser)
192 Q 57 (Nick Winser)
193 Q 120 (Graham Stuart MP)
194 Parliamentary Office of Science and Technology, *Green skills in education and employment*, POSTnote 711, January 2024
195 Q 26 (Professor Pam Thomas)

can be put together for the people we would need."[196] Martin Scargill echoed this, saying that these skills were "an extension of what we have relied on for decades in the oil and gas industry. … The skills are very much the same. We just need more of them".[197]

123. However, Daniel Murrant told us that "even if we wanted to roll out a hydrogen network tomorrow, we do not have the skills to do that as quickly as we would like".[198] Simon Virley identified the skills shortfall as a "major barrier", saying that "we need a major step up in skills and training to create the number of electrical engineers, hydrogen engineers and others who will be needed."[199]

124. Professor Bruce noted that this will affect the investment decisions of firms: "It is no good simply asking businesses to bid to operate salt caverns. Unless they know that … skilled people will be there to operate these things, it does not make a sensible business case."[200] Tim Lord suggested that there was a reciprocal relationship between investment decisions and skills provision, stating that "you cannot do this only by pushing the supply side; you have to have the pipeline of projects and credible investment instruments that those projects might get built. That will then create the incentives for private sector developers and investors to invest in skills to get them built."[201]

125. David Gray told us that part of the challenge with respect to skills was identifying the specific skills shortages: whilst "we have a range of areas where we know that we will have locally specific jobs … there is a whole range of jobs where perhaps people do not fully understand the vision and the connection of those roles with meeting the decarbonisation challenge that we face."[202]

126. **As with many other Net Zero ambitions, the availability of relevant skills, including all types of engineers and particularly those with experience of hydrogen, will be a barrier to scaling up technologies.**

127. ***The Government should work with industry to determine and set out an assessment and estimate of the numbers of skilled individuals that will be needed to deliver on its hydrogen targets, and across which professions, and work with industry to fund training and retraining programmes accordingly. Training skilled individuals has the longest lead time and so needs to be happening now if projects are to scale up.***

Minimising the need for long-duration energy storage

128. As discussed in chapter 3, there is a range of estimates for how much storage will be needed on a decarbonised grid. Michael Liebreich explained that there are "other ways in which we can balance things" and we are likely to "do those first because they are cheaper", especially "under … 48 hours", citing demand flexibility, thermal storage, and interconnectors.[203]

196 Q 36 (David Surplus)
197 Q 62 (Martin Scargill)
198 Q 7 (Daniel Murrant)
199 Q 49 (Simon Virley)
200 Q 15 (Professor Sir Peter Bruce)
201 Q 49 (Tim Lord)
202 Q 45 (David Gray)
203 Q 68 (Michael Liebreich) he was clear in this answer that in his opinion alternatives do not eliminate the need for on the order of 20 TWh of long-duration storage.

129. **Long- and medium-duration energy storage for the electricity system will be critical for a fully decarbonised grid, but it will not always be the cheapest option: energy efficiency, thermal energy storage, demand-side response and interconnectors can minimise our reliance on energy storage, especially on shorter timescales.**

Demand flexibility

130. Rachel Hay said that a strategy for a decarbonised electricity system by 2035 should cover "the full range of low-carbon flexibility options [including] demand flexibility."[204] Ita Kettleborough explained that "hot water storage in houses" was an example of demand that could be shifted to hours with higher generation.[205] Caroline Still said that "car batteries [are] a form of demand-side flexibility" that "can provide a reduction in peak demand … through smart charging."[206]

131. Some demand-side response projects, such as the Demand Flexibility Service (DFS), are already underway.[207] In the DFS, the ESO publishes an indication of need for demand to be reduced between certain hours the next day or later the same day. Participation depends on having a smart meter and an energy supplier being part of the scheme.

132. To incentivise consumers to use energy flexibly, Tom Lowe of Thermal Storage UK told us we need "smart time-of-use tariffs" and to "encourage" or "mandate" energy retailers to offer them. To make these viable, he said "we need to complete the smart meter rollout [and] move to market-wide half-hourly settlement, which we are expecting in 2026."[208] This would allow tariffs to change with the time of day and thereby respond to supply and demand.

133. Michael Liebreich set out a scenario for more extreme demand-side management—during extremes of low wind and solar generation like the "dark doldrums", when there is an extended period of low wind speeds in winter, "you can also switch off the electrolysers, refineries … industrial uses of power that can be switched off at large scale when you need to."[209] Claire Dykta explained that, with appropriate compensation, "heavy, intensive industrial users could change their processes" to use power at optimum times. This could reduce peaks in demand and hence the amount of storage generating capacity needed.[210]

134. **Flexible demand can help to smooth out variations across hours and days. In extreme cases of low generation, it may help balance the system if electrified industries shut down temporarily to reduce peak demand, but it does not seem that mechanisms for this have been explored. However, there could also be demand-side risks, such as a "run on the plugs", for example if a much higher than normal number**

204 Q 101 (Rachel Hay)
205 Q 39 (Ita Kettleborough)
206 Q 4 (Caroline Still)
207 ESO, 'Demand Flexibility Service: What is the Demand Flexibility Service': https://www.nationalgrideso.com/industry-information/balancing-services/demand-flexibility-service-dfs [accessed 10 January 2024]
208 Q 24 (Tom Lowe)
209 Q 69 (Michael Liebreich)
210 Q 56 (Claire Dykta) and written evidence from National Grid Electricity System Operator (LES0032)

of drivers decide to charge their electric vehicles simultaneously due to concerns over supply.

135. ***The Government should build on initiatives from the National Grid Energy System Operator like the Demand Flexibility Service, expanding them and making them permanent. This should involve a robust programme of consumer research to ensure people who provide flexibility are incentivised, rewarded, and protected appropriately, but also to understand any potential flaws in how the system works in practice in a range of circumstances. The Government should support the roll-out of market-wide half-hourly settlement, which will help energy companies offer electricity tariffs that encourage people to operate appliances flexibly. It should explore the potential for more serious demand-side interventions where supply is extremely limited.***

Interconnectors

136. Electricity network interconnectors have been successfully expanded to support the grid and allow for import and export.[211] Simon Virley said that "we have seen cap and floor work for interconnectors … [with] long lead times, high capital expenditure requirements, and an uncertain operating environment."[212] However, Daniel Murrant noted that "they are very important, but … European weather cycles are broadly similar to ours and there are potentially also political issues" with relying on them instead of domestic long-duration energy storage.[213]

137. We heard concerns from Statera Energy that "since leaving the European Union, the GB market has decoupled from the EU market", resulting in "explicit trading" which is "far less efficient."[214] Correlated weather cycles across Europe means that renewable supply from wind is likely to be low across the continent at the same time, and so we cannot rely on importing from neighbours. Michael Liebreich set out the possibility of intercontinental interconnectors "further than Europe … to places that are north-south and so have very different weather patterns, or east-west and so have very different time zones".[215]

138. **Interconnectors with other countries can reduce, but not eliminate, the need for energy storage and curtailment on the grid and could allow us to export our storage capacity. There are security and political risks associated with over-reliance on interconnectors, especially in an energy crisis which is likely to be Europe-wide. The Government's ambition to more than double interconnector capacity by 2030 is welcome and successful deployment so far demonstrates the value of cap-and-floor subsidies.**

211 By 2024 interconnectors will have a capacity of 7.8 GW (15% of UK demand) and in 2022 they supplied around 13.7 TWh of electricity to the UK. See National Grid, 'What are electricity interconnectors?': https://www.nationalgrid.com/stories/energy-explained/what-are-electricity-interconnectors [accessed 10 January 2024]. This capacity has trebled since 2010, see Department for Business, Energy and Industrial Strategy, *Electricity interconnectors in the UK since 2010* (June 2022): https://assets.publishing.service.gov.uk/media/62bb2816d3bf7f662753cfa8/Electricity_interconnectors_in_the_UK_since_2010.pdf [accessed 10 January 2024]
212 Q 48 (Simon Virley)
213 Q 3 (Daniel Murrant)
214 Written evidence from Statera Energy (LES0023)
215 Q 69 (Michael Liebreich)

139. ***The Government should pursue expansion of GB interconnectors as part of its energy security strategy, ensuring we can trade efficiently with the EU market. It should explore the potential for interconnectors that could help manage seasonal demand and mitigate risks from weather systems that extend across Northern Europe, by connecting further afield with EU Member States, such as Southern European States, as well as the Middle East and North Africa.***

Thermal storage

140. Tom Lowe of Thermal Storage UK said that thermal storage has "a role in the 24-hour use case" to "reduce … peak demand".[216] He also explained that "if we electrify heating, we will be putting in thermal stores with heat pumps anyway. You may as well use them as much as possible for grid management"[217] whereby electrified heating is used to heat water or thermal stores at off-peak times to release heat later.

141. Mr Lowe set out some examples of pilot projects, including one for "industrial heat processes", which have been funded by Government.[218] However, he also highlighted some aspects of Government policy where the flexibility provided by thermal stores was not fully considered, including VAT, energy performance certificates, and inclusion in the boiler upgrade scheme.[219]

142. **Thermal energy storage, both domestically and as part of heat networks, could play a significant role. It can shift peak demand times and help with the integration of electrified heating such as heat pumps. A few small-scale projects have been supported through the Longer Duration Energy Storage Demonstration Programme, but we encourage the Government to do more to support thermal energy storage.**

143. ***Ofgem and the Future System Operator should identify ways of incentivising businesses and households to provide flexible heating that can support the grid. Thermal storage and an assessment of flexibility should be included in existing policy mechanisms, such as Energy Performance Certificates, the Energy Saving Materials technology list for VAT relief, grants such as the Boiler Upgrade Scheme, and the Clean Heat Market Mechanism.***

The roles of different actors in the energy system

144. Witnesses told us that one challenge is the number of organisations that have a potential role in delivering long-duration energy storage; the ESO's Claire Dykta said that "there are lots of different bodies and, historically, the energy system has been quite siloed in how it thinks and how it operates."[220]

145. Whilst there will be a number of issues that these organisations will need to address, we heard that the Future System Operator in particular will face a unique task of balancing supply and demand on the grid, requiring a greater

216 Q 20 (Tom Lowe)
217 Q 21 (Tom Lowe)
218 Q 25 (Tom Lowe)
219 Q 24 (Tom Lowe) and written evidence from Thermal Storage UK (LES0004)
220 Q 54 (Claire Dykta)

degree of flexibility. Matt Harper set out the challenge:

> "The difficulty is that the electric grid was constructed around a very centralised model with huge energy facilities. … We are now in a world where the grid is more decentralised. More of the assets that are coming out of the grid are not available on command. What the grid operators are struggling with is to maintain that same level of absolute low-cost reliable power in a world where they have less and less control over how those generating assets are operated."[221]

146. Ms Dykta recognised that the FSO's remit, powers and responsibilities needed to be clearly set out, telling us that "There is an awful lot of work going on … between … the electricity system operator, the government department and the regulator Ofgem to define the lines of responsibility and how things will move forward." The Energy Bill will provide for certain duties; alongside this there will be a "more informal … advisory role that … provides advice to the Government on the development of policy."[222]

147. Nick Winser said that "a plan that all … stakeholders can focus on, well defined in terms of the responsibilities for its delivery and endorsement, will provide a focal point".[223] Dr David Joffe told us that "formalis[ing] the institutional responsibilities of the future system operator, Ofgem and the Government in delivering this system" was also one of the Climate Change Committee's recommendations. It recommended that there should be "a Minister-led infrastructure delivery group to ensure that these things are moving forward."[224]

148. Asked about the number of actors involved in the net zero transformation, DESNZ officials told us that

> "the Government's role is to set the policy direction. Ofgem is the independent regulator … and it makes decisions on business and investment plans. We see the future system operator as the whole-system planner, the operator of the electricity system and an expert adviser to the Government and Ofgem as the key decision-makers."[225]

149. The Minister told us that "we are also developing a framework agreement that will set out the relationship between government as shareholder and the FSO, which we plan to publish shortly after designation" to provide more detail on governance questions.[226]

150. **There are many actors with a role in delivering long-duration storage, from the Department of Energy Security and Net Zero, Ofgem, the proposed Future System Operator, energy companies, the electricity transmission network owners and so on. In particular, the FSO has a potentially difficult role in coordinating and balancing supply and demand on a grid that is larger, more complex, decentralised and variable than before. There is a need for an overall "guiding mind" with the authority to take decisions and coordinate actions.**

221 Q 38 (Matt Harper)
222 Q 54 (Claire Dykta)
223 Q 54 (Nick Winser)
224 Q 100 (Dr David Joffe)
225 Q 98 (Emily Bourne)
226 Q 122 (Graham Stuart MP)

151. ***The Government must ensure that stakeholder organisations coordinate their efforts, that responsibilities and remits are clearly delineated and foster a shared vision of how the future energy system should look and how to get there. The role and powers of the Future System Operator and the Secretary of State need to be clarified, especially with respect to ensuring resilience and security of energy supply, and the FSO needs to be appropriately empowered and resourced to fulfil its mandate.***

Transmission networks and the Strategic Spatial Energy Plan

152. As well as connecting individual projects to the grid, strategic transmission network capacity is important. Ita Kettleborough explained that "Transmission and distribution become critically important when you have a renewable-dominated system, because where the wind blows best might not be where the consumption is. You have to move the electrons around more."[227] The Royal Society quoted a National Grid estimate that Net Zero would require £100 billion in investment between now and 2050 to enlarge and strengthen the transmission grid.[228] The Government set out in its Transmission Acceleration Action Plan its response to the recommendations made by the Electricity Networks Commissioner to halve the timeline for constructing strategic transmission infrastructure from 14 years to 7 years.[229]

153. Timothy Armitage said "We need to co-locate our storage effectively with hydrogen production and demand … [we need] an integrated system with overall master planning and a direction of travel that everybody can buy into."[230] Dr David Joffe described the need for decisions to be made in hydrogen infrastructure as well: "we have a pretty good idea of where the hydrogen storage might be, because only certain geologies are suitable to host salt caverns. But in order to make the infrastructure investments, we need to know at a transmission level what we are joining up."[231]

154. **Transportation and transmission networks for hydrogen and electricity will need to be substantially improved and expanded. There is a need for sensible coordination in the design of hydrogen and electricity systems. Co-locating electrolysers and hydrogen-to-power generation with storage seems the most efficient option, but this will require significant electricity transmission infrastructure connecting storage sites to generation and to the grid. Hydrogen pipelines could connect storage to planned hydrogen industrial hubs. Without some assurance around how transmission networks will evolve, it will be hard for investors to make large-scale investment decisions into storage.**

155. The Electricity Networks Commissioner recommended that a Strategic Spatial Energy Plan (SSEP) should be developed (and regularly refreshed), that would translate high-level targets into specific volumes in specific

227 Q 43 (Ita Kettleborough)
228 The Royal Society estimated 100 terawatt-hours (TWh) of storage would be needed. See Royal Society, *Large Scale electricity storage* (September 2023), box 1: https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/Large-scale-electricity-storage-report.pdf [accessed 10 January 2024]
229 Department for Energy Security and Net Zero, *Transmission Acceleration Action Plan* (November 2023): https://assets.publishing.service.gov.uk/media/65646bd31fd90c0013ac3bd8/transmission-acceleration-action-plan.pdf [accessed 10 January 2024]
230 Q 30 (Timothy Armitage)
231 Q 102 (Dr David Joffe)

locations.[232] The Government said in its Transmission Acceleration Action Plan that it "broadly supports" the SSEP and "work has already begun", and that "in early 2024, we will commission the Energy System Operator … to work with government to develop the SSEP", and that "the first iteration of the plan will focus on power and hydrogen assets."[233]

156. Witnesses supported a spatial plan; Emily Bourne explained that the plan was needed "to give that level of certainty, which does not exist at the moment" about energy policy, and said DESNZ was "working with Ofgem, the system operator and other departments to design that process" by which the plan would be developed.[234]

157. Nick Winser laid out further ways in which having an overall strategic plan would assist the energy system transformation: "A strategic plan will also help projects, both on the network and on storage, to go through the planning process… It will also enable us to look at whether we think we have the right market and regulatory signals in place to get each part of the plan delivered, mainly by private investment."[235]

158. The Electricity System Operator warned of a "disjointed approach to spatial planning" without a clear strategy.[236] Michael Liebreich said "the idea that the market will figure out energy choices does not work … having a strategy is a necessity" but that we must "make sure that the strategy does not obliterate price signals."[237] There is considerable urgency in finalising this plan: Dr David Joffe said that we need a plan "ideally yesterday or the day before" for "making strategic decisions across the energy system for these long lead-time investments."[238]

159. Owen Bellamy of the Climate Change Committee described an SSEP as "a useful and a worthwhile addition" to an "overarching strategy." However, he said it must be "done in a sequenced and co-ordinated way because there is a range of issues that only the Government can take strategic decisions on, and [the] planner … will not necessarily be able to". He said that the process of planning needs to identify "strategic priorities" and the plan "needs to go down to the level where you can make infrastructure decisions", so "at least regional and possibly down to the local level as well."[239]

160. Nick Winser and Claire Dykta spoke of the Government "endorsing" the plan to ensure other actors took it seriously, although Mr Winser admitted that "there is a lot of debate to be had about what is meant by 'endorse'".[240] When asked if the plan would have statutory weight, DESNZ's Emily Bourne said it was being "actively considered."[241]

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232 Catapult, *Electricity Networks Commissioner—Companion Report Findings and Recommendations* (June 2024): https://assets.publishing.service.gov.uk/media/64c8e85219f5622360f3c0ee/electricity-networks-commissioner-companion-report.pdf [accessed 10 January 2024]
233 Department for Energy Security and Net Zero, *Transmission Acceleration Action Plan* (November 2023): https://assets.publishing.service.gov.uk/media/65646bd31fd90c0013ac3bd8/transmission-acceleration-action-plan.pdf [accessed 10 January 2024]
234 Q 85 (Emily Bourne)
235 Q 53 (Nick Winser)
236 Written evidence from Electricity System Operator (LES0044)
237 Q 76 (Michael Liebreich)
238 Q 102 (Dr David Joffe)
239 Q 102 (Owen Bellamy)
240 Q 55 (Nick Winser and Claire Dykta)
241 Q 98 (Emily Bourne)

161. The Minister told us that the Strategic Spatial Energy Plan will feed into future plans: it will "enable the creation of a transmission network blueprint in the centralised strategic network plan, which will be produced by the FSO." He said that the SSEP would "define the optimal location, generation and infrastructure required to meet forecast demand and our 2050 targets" and that the FSO would "develop the SSEP using policy inputs and priorities provided by [the Government], including technology-specific targets, with oversight from the regulator."[242] The Minister did not commit to a specific date, but Emily Bourne said that "The aim is for the first strategic spatial energy plans to be produced in time to inform the centralised strategic network plan… in 2025–26."[243]

162. On whether the plan should be statutory, the Minister said "we can look at whether we need to make it statutory or to bring in any specific enforcement or alignment with national policy statements and the like" in the case that "we do not think it can do its job simply through joint publication [and] consultation."[244]

163. Ms Bourne said that in the "commission that we are developing at the moment, we are looking at the governance" for how a Strategic Spatial Energy Plan would be implemented.[245] The Minister told us that "the democratically elected Government will need to approve this", but he hoped the FSO's report would have "enormous weight" and that there would be a "proper, grown-up, mature approach to make sure that we are on the same page."[246]

164. ***There is an urgent need for key strategic decisions and investment into the transportation networks for both electricity and hydrogen. These network decisions should support the deployment of large-scale long-duration energy storage and a strategic energy reserve. These decisions should be communicated as part of the Strategic Spatial Energy Plan and delivered by a cross-departmental Ministerial Working Group, as currently exists for electricity network transmission infrastructure.***

165. **We welcome the commitment to develop a Strategic Spatial Energy Plan, which is critical for long duration energy storage, but details remain unclear. We are unclear about the level of detail—for example, whether the Plan will be at the regional level or identify major facilities—as well as who will take responsibility for delivering on the plan once it has been developed by the Future System Operator. It is also unclear whether the plan will be given a statutory basis and how it will fit within the planning system. There is a risk that the Future System Operator develops a plan with substantial implications for national infrastructure and public expenditure, requiring coordinated action from many actors in the energy system, which the Government does not fully commit to, and so there is a lack of follow-through. 'Endorsement' of the plan may not be enough.**

242 Q 117 (Graham Stuart MP)
243 Q 117 (Emily Bourne)
244 Q 117 and Q 118 (Graham Stuart MP)
245 Q 119 (Emily Bourne)
246 Q 119 (Graham Stuart MP)

166. ***The Strategic Spatial Energy Plan should include locations for long-duration energy storage and the supporting infrastructure. It must include provisions that support the Government's targets for hydrogen, and address the need for long-duration energy storage on the grid and a strategic reserve. It should be developed iteratively, and updated at regular intervals, with close collaboration between the FSO, Ofgem and the Government.***

167. ***The Future System Operator needs to be sufficiently empowered and resourced to develop a credible plan. As it does so, it must identify the key strategic, infrastructure and investment decisions that the plan entails. These decisions must then be made swiftly by the Government, which must then commit to ensure every actor in the system is working to deliver on them. Ofgem should endorse it in line with its Net Zero mandate.***

168. ***We urge the Government to publish timelines for developing the plan and details of what it will contain as soon as possible. It should consider whether a statutory basis for the plan is needed to ensure it is carried out.***

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. Energy storage can provide benefits to the grid. It can reduce curtailment and grid congestion, avoiding wasting energy and reducing the cost of renewable electricity. Energy storage facilities provide power that can be turned on and off at will, enhancing grid flexibility. Long-duration energy storage therefore reduces costs elsewhere in the system and allows a greater proportion of cheap renewables to be built and so reduces electricity prices overall. (Paragraph 11)

2. Domestic energy storage is not just about a resilient decarbonised grid—it is about the security and stability of the whole economy. The global energy crisis that began in 2021 has been an object lesson in the UK's vulnerability to global wholesale energy price fluctuations, and the consequent effects on inflation. The UK had less storage capacity than comparator nations and came to regret and partially reverse its closure of the Rough gas storage facility. (Paragraph 12)

3. The UK is currently a net importer of gas for heating and power. With storage, it can develop sufficient offshore renewable generation to be more energy self-sufficient and better insulated from future global shocks. The UK could export its hydrogen and sell its energy storage capacity and expertise internationally if it develops a leading position. (Paragraph 14)

4. A fully decarbonised electricity system will need substantial energy storage across a range of timescales due to increasing variability of supply and demand in an electrified, renewable-powered economy. Estimates of how much long-duration energy storage will be needed differ depending on assumptions about future energy mix, demand, future climate and desired resilience. These assumptions affect, but do not eliminate, the need for long-duration energy storage. (Paragraph 34)

5. However, there is a consensus that tens of terawatt-hours of long-duration electricity storage will be needed to decarbonise the grid, but the Government has not committed to an explicit target. This is several orders of magnitude more low-carbon storage than the UK currently has and will require different technologies from those currently used, such as the 10 TWh of natural gas storage, to be compatible with Net Zero. (Paragraph 24)

6. The Government should, as a matter of urgency, set an explicit minimum target for how much "no-regrets" long-duration energy storage and generating capacity it wants to see operational by 2035. It should set out a credible timescale with interim milestones for achieving this that works backwards from 2035, accounting for decision time, planning and consenting, and construction of facilities. It should also expand on the 30 GW target of short-term storage, interconnection and demand-side response set out in the Smart Systems and Flexibility Plan by outlining the minimum contribution to flexibility that each technology should make. (Paragraph 25)

7. For energy storage systems, energy stored, typical storage duration, final output electrical energy, and the instantaneous power that can be delivered are important parameters. (Paragraph 26)

8. Government policies and targets relating to energy storage—such as the 10 GW hydrogen production target—should make clear both the power (GW) and the energy (TWh) it is intended to produce and store. (Paragraph 26)

9. A range of energy storage technologies will be needed for different energy system services. We are concerned that the excessive policy and investment focus on lithium-ion storage projects has left policymakers, investors and regulators less able to appreciate the need for longer-duration technologies. There is a clear distinction between technologies which perform best across hours and for daily variations ("medium-duration energy storage"), and technologies which can store energy across days, weeks and months ("long-duration energy storage"), which a definition of long-duration energy storage as anything greater than six hours may not capture. (Paragraph 31)

10. The Government, supported by modelling from the Future System Operator, should clarify its definitions for medium- and long-duration energy storage and the roles they are expected to play. It should set or endorse a series of metrics that allow technologies to be compared according to the energy system services that they provide. It should use these to publish an Assessment of Likely Need for long-duration energy storage by the end of 2024; this should include storage timescales, energy stored and power capacity required. It should commit to supporting a range of technologies, beyond just batteries, through financial support mechanisms and research grants for less mature technologies. (Paragraph 32)

11. There are long lead-in times for delivering energy storage—typically estimated around 7–10 years for most technologies. If the Government waits until there is a clear picture of exactly how supply, demand and the energy system will evolve, it cannot possibly develop storage in time for a decarbonised grid by 2035. (Paragraph 35)

12. The Government should focus on "pace not perfection" in delivering no-regrets projects—it is always possible to iterate on policy as uncertainties are resolved. It should bring forward its support schemes and no-regrets investments as soon as possible. (Paragraph 35)

13. The economics of long-duration energy storage projects are challenging and they will require additional financial support mechanisms. Our witnesses generally favoured a cap and floor mechanism, and we are pleased to see the Government is actively consulting on introducing one. The Government has also stated that it is "minded to" provide a revenue floor for hydrogen transportation and storage but how this will interact with the proposed long-duration energy storage cap and floor subsidy is unclear. Hydrogen and electricity policies should be considered and designed together. (Paragraph 46)

14. The Government should, as a matter of urgency, finalise and set out the details of its business models to support commercial long-duration energy storage. We recommend that cap and floor support mechanisms are designed to support technologies that supply energy across different timescales, recognising the distinction between those that store energy for up to 24 hours and those that can store energy over days and weeks. The Government should clarify which technologies it considers to be eligible for the streams at different readiness levels, and whether the long-duration energy storage support mechanisms will be open to hydrogen. We recommend that hydrogen facilities intended for long-duration storage should be eligible for support and that the Government should resolve any overlaps between its policies. (Paragraph 47)

15. The funding allocated to this business model must be sufficient to support deployment at scale, in line with its aim to balance the overall system, and the Government should outline the scale of funding that will be associated with its support schemes. We recommend that minimum targets for the overall long-duration energy storage capacity the model should support will help ensure support mechanisms are set appropriately to bring forward the necessary scale and range of projects. (Paragraph 48)

16. The National Infrastructure Commission has recommended a strategic reserve of 25 TWh of electricity storage by 2040. Since the economic incentive is to cycle storage often, there is a concern over how to ensure commercially operated storage is available when it is needed most. Maintaining reserve storage will likely not be profitable even with a cap and floor subsidy. The Government has not made a clear commitment to developing a strategic reserve or explained whether it thinks green hydrogen or natural gas will fulfil that role. It has not explained how it will respond to generation shortfalls without a strategic reserve, or how it will replace the storage capacity provided by Rough. (Paragraph 57)

17. The Government should commit to, and develop plans for, a strategic reserve of energy storage alongside commercially operated storage on the scale suggested by the National Infrastructure Commission. This could be in the form of facilities owned and operated by the Government or strategic reserve storage capacity could be contracted out. If the Government intends to procure strategic reserve energy storage, it needs to work with industry to set out procurement terms and a scale of funding that will ensure a stable reserve and security of supply. (Paragraph 58)

18. If unabated natural gas is to play a role, the Government must explain how this is compatible with climate change targets, in particular the Sixth Carbon budget and a decarbonised electricity system by 2035. If it will not pursue a strategic reserve, it must explain how the energy system will respond to shortfalls of renewable generation such as those highlighted by the Royal Society. (Paragraph 59)

19. Although many of the components of a facility used to generate, store and convert hydrogen back into electricity are technologically mature, there are no facilities that do all three at scale in the UK. A large-scale demonstrator could help to "de-risk" investment by serving as a successful model for later projects to follow. The Committee welcomes the announcement that two projects will be supported under the hydrogen transportation and business model, but the scale of these projects is unclear. (Paragraph 65)

20. The Government should, as soon as possible, identify a portfolio of "no-regrets" investments into long-duration energy storage projects. This should include commissioning a pilot project that combines onsite electrolysis, hydrogen storage in salt caverns (on the scale of hundreds of GWh) and electricity generation from hydrogen. Ideally, this should be a part of, or close to, the existing hydrogen clusters. Lessons learned from this project, in terms of what is required in skills, planning and capital/operational costs should be published as the project progresses to develop policy and de-risk future projects. The Government should set out the scale of storage of the projects it intends to support with its hydrogen transportation and storage business model. (Paragraph 66)

21. We heard that there could be some scope for repurposing gas storage facilities to store hydrogen in the future. This is at a lower technology readiness level than purpose-built salt caverns for storing hydrogen, which have been deployed before, but may be faster to develop. (Paragraph 69)

22. **The Government should work with Centrica to understand its proposed project to repurpose the Rough gas storage facility for hydrogen, with a view to determining, by the end of 2024, whether it will support this project.** (Paragraph 69)

23. We welcome the Government's ambitious target for 10 GW of clean hydrogen by 2030. However, clarity over the role of hydrogen is needed to decide on key details of storage and transportation infrastructure. Credible forecasts of demand for hydrogen would help investors to commit. We heard that decarbonising hydrogen-using industries and long-duration energy storage are good uses for low-carbon hydrogen, while domestic heating and light transport may be a distraction. (Paragraph 74)

24. **The Government needs to clarify the role it sees for hydrogen on the future energy system assuming its target is met, with an indication of how the clean hydrogen produced in 2030 will be used. It should bring forward the decision on whether hydrogen will be used in domestic heating from 2026—we advise against it. Hydrogen use should also be ruled out in locations and for applications that would be prohibitively expensive or without supporting infrastructure.** (Paragraph 75)

25. Meeting hydrogen targets will require substantial additional electrolyser capacity, which could become a serious production bottleneck for hydrogen if not addressed. We heard that there is strong international competition for such capacity, notably from the EU and US which have significant hydrogen subsidies. (Paragraph 78)

26. **The Government should set out in its response to this report how it intends to obtain sufficient electrolyser capacity to meet its hydrogen production targets and ensure its approach supports domestic manufacture and research and development.** (Paragraph 78)

27. Industry has significant experience with using hydrogen as an industrial gas and there do not appear to be major safety concerns. (Paragraph 79)

28. We heard no evidence to suggest that hydrogen is unsafe, especially when used as an industrial gas. However, the public perception of safety is vital, as negative perceptions of hydrogen projects could prove to be an obstacle in the planning process. We were disappointed that the Government does not seem to recognise this distinction or its crucial role in securing public support, and the Government has work to do to explain the role of hydrogen and its safety profile to the public. (Paragraph 85)

29. **DESNZ should commission research in the next six months into the public acceptability of hydrogen storage, in particular in the local communities which are most likely to host it. A public information and dialogue campaign that explains the envisaged role for hydrogen, as well as its safety aspects, is essential and must be a priority for the Government—it cannot be left to developers. The campaign should emphasise the importance and benefits of these energy infrastructure projects for national and economic security, as**

well as the industry experience with producing and using large volumes of hydrogen today. (Paragraph 86)

30. Some uncertainties remain around some of the operating and safety parameters for hydrogen storage—for example, the potential for microbial production of hydrogen sulphide. (Paragraph 87)

31. **The Government should work with UKRI to commission research into the safety aspects of hydrogen storage and transportation, as well as the public acceptability of hydrogen transport and storage facilities.** (Paragraph 88)

32. Pumped-storage hydropower could play a valuable role in partially fulfilling medium-duration storage needs. We heard from the pumped-storage hydropower industry that a pipeline of projects is at various stages of development but will require additional support mechanisms to proceed. Projects could take seven or more years to construct, so final investment decisions are urgent if they are to be ready by 2035. (Paragraph 92)

33. **The Government should consult with the pumped-storage hydropower industry to determine the levels of the cap and floor support mechanism that might be needed to support projects that already have planning permission. Projects that can demonstrate their cost-effectiveness should be supported by the long-duration energy storage business model.** (Paragraph 93)

34. Advanced compressed air energy storage (ACAES) could store energy on the timescale of 4–24 hours and help to manage medium-term variations in demand. However, as a relatively new technology, cost estimates vary widely. The Royal Society found that the availability of some CAES could reduce overall costs for the energy system under some circumstances if it can cycle quickly. (Paragraph 96)

35. **The Government should investigate the costs and efficiencies of large ACAES, for example through researching comparable systems that have been operated in other countries, with a view to supporting them through the long-duration energy storage business model in 2024.** (Paragraph 96)

36. Lithium-ion batteries have been a central focus of battery development in the UK because of their uses in the automotive sector, but alternative chemistries such as flow batteries or iron-air batteries will be more suitable for medium-duration grid-scale storage across multiple days. The UK has some pilot projects for flow batteries which could be expanded. (Paragraph 100)

37. **The Government's industrial battery policy should outline a clearer role for flow batteries and iron-air batteries that might have grid-scale applications. The Faraday Institution and related battery R&D funding initiatives should be expanded to enable dedicated funding to chemistries that can be useful for grid-scale storage.** (Paragraph 101)

38. **Early-stage technologies like ACAES, flow batteries, and large-scale thermal storage would benefit from the commission of large-scale demonstration projects and the Government should consider co-funding some large-scale pilot projects with industry.** (Paragraph 102)

39. There is agreement that a mix of technologies is likely to be needed for long-duration energy storage. Hydrogen is likely to be the best solution for storage across multiple weeks and months, but there is a range of competing technologies for storage across hours and days, which can also provide different

services to the grid. Long-duration energy storage developers argue that the overall value they provide to the grid in terms of electricity system services is not yet properly incentivised, meaning the revenue stack for projects does not always add up. More information about how the Future System Operator will procure energy system services would encourage investment and healthy competition. Financial support mechanisms and market arrangements should be designed support a mix of storage technologies that provide the services the grid needs. (Paragraph 108)

40. The Government, supported by the Future System Operator and as part of its planning, should incentivise the right mix of technologies by specifying in detail which energy system services it wants to procure, including storage capacity and duration, in line with the Assessment of Likely Need. This should include suggested levels of payment and published modelling should project the likely levels of demand so that revenue streams can be forecast. Energy storage projects that can provide additional services to the grid should be incentivised to do so by receiving additional payments above the "revenue floor" if they are eligible for the commercial long-duration energy storage cap and floor mechanism. (Paragraph 109)

41. We heard from would-be long-duration energy storage project developers that connecting to the grid is a barrier that can prove fatal to projects. The Committee welcomes the recent announcement that Ofgem is reforming the queue to remove non-viable projects, as well as the reforms proposed in the Connection Action Plan. This will be critical to ensuring a pipeline of projects can be developed in time. (Paragraph 113)

42. Ofgem and the ESO should reduce the grid connection queue urgently and speed up timelines to connect projects to the grid. They should publish updates on how the reforms are progressing reducing the queue of proposed projects. They should consider prioritising storage projects for accessing the queue given their additional benefits such as alleviating grid constraints as well as acting as flexible generation. (Paragraph 114)

43. We have heard that obtaining planning permission for energy storage facilities can be difficult and add significantly to timelines. It is not clear that the planning system has distinct guidance for energy storage facilities as opposed to energy generation. There currently is no regulatory licensing regime for the onshore storage of hydrogen, so developers need additional guidance from Government. (Paragraph 119)

44. The planning system must be reformed and sufficiently resourced to deal with the additional strain on it from new energy projects. It must recognise storage for its own value for energy system resilience by the end of 2024. The Government, working closely with Ofgem, should identify and set out the regulatory barriers to storage project developments and explain what actions it will take to address them. This should include more detailed guidance for developers on navigating the planning system, as well as clarifying how onshore storage of hydrogen will be regulated and licensed. (Paragraph 120)

45. As with many other Net Zero ambitions, the availability of relevant skills, including all types of engineers and particularly those with experience of hydrogen, will be a barrier to scaling up technologies. (Paragraph 126)

46. The Government should work with industry to determine and set out an assessment and estimate of the numbers of skilled individuals that will be

needed to deliver on its hydrogen targets, and across which professions, and work with industry to fund training and retraining programmes accordingly. Training skilled individuals has the longest lead time and so needs to be happening now if projects are to scale up. (Paragraph 127)

47. Long- and medium-duration energy storage for the electricity system will be critical for a fully decarbonised grid, but it will not always be the cheapest option: energy efficiency, thermal energy storage, demand-side response and interconnectors can minimise our reliance on energy storage, especially on shorter timescales. (Paragraph 129)

48. Flexible demand can help to smooth out variations across hours and days. In extreme cases of low generation, it may help balance the system if electrified industries shut down temporarily to reduce peak demand, but it does not seem that mechanisms for this have been explored. However, there could also be demand-side risks, such as a "run on the plugs", for example if a much higher than normal number of drivers decide to charge their electric vehicles simultaneously due to concerns over supply. (Paragraph 134)

49. The Government should build on initiatives from the National Grid Energy System Operator like the Demand Flexibility Service, expanding them and making them permanent. This should involve a robust programme of consumer research to ensure people who provide flexibility are incentivised, rewarded, and protected appropriately, but also to understand any potential flaws in how the system works in practice in a range of circumstances. The Government should support the roll-out of market-wide half-hourly settlement, which will help energy companies offer electricity tariffs that encourage people to operate appliances flexibly. It should explore the potential for more serious demand-side interventions where supply is extremely limited. (Paragraph 135)

50. Interconnectors with other countries can reduce, but not eliminate, the need for energy storage and curtailment on the grid and could allow us to export our storage capacity. There are security and political risks associated with over-reliance on interconnectors, especially in an energy crisis which is likely to be Europe-wide. The Government's ambition to more than double interconnector capacity by 2030 is welcome and successful deployment so far demonstrates the value of cap-and-floor subsidies. (Paragraph 138)

51. The Government should pursue expansion of GB interconnectors as part of its energy security strategy, ensuring we can trade efficiently with the EU market. It should explore the potential for interconnectors that could help manage seasonal demand and mitigate risks from weather systems that extend across Northern Europe, by connecting further afield with EU Member States, such as Southern European States, as well as the Middle East and North Africa. (Paragraph 139)

52. Thermal energy storage, both domestically and as part of heat networks, could play a significant role. It can shift peak demand times and help with the integration of electrified heating such as heat pumps. A few small-scale projects have been supported through the Longer Duration Energy Storage Demonstration Programme, but we encourage the Government to do more to support thermal energy storage. (Paragraph 142)

53. Ofgem and the Future System Operator should identify ways of incentivising businesses and households to provide flexible heating that can support the

grid. Thermal storage and an assessment of flexibility should be included in existing policy mechanisms, such as Energy Performance Certificates, the Energy Saving Materials technology list for VAT relief, grants such as the Boiler Upgrade Scheme, and the Clean Heat Market Mechanism. (Paragraph 143)

54. There are many actors with a role in delivering long-duration storage, from the Department of Energy Security and Net Zero, Ofgem, the proposed Future System Operator, energy companies, the electricity transmission network owners and so on. In particular, the FSO has a potentially difficult role in coordinating and balancing supply and demand on a grid that is larger, more complex, decentralised and variable than before. There is a need for an overall "guiding mind" with the authority to take decisions and coordinate actions. (Paragraph 150)

55. The Government must ensure that stakeholder organisations coordinate their efforts, that responsibilities and remits are clearly delineated and foster a shared vision of how the future energy system should look and how to get there. The role and powers of the Future System Operator and the Secretary of State need to be clarified, especially with respect to ensuring resilience and security of energy supply, and the FSO needs to be appropriately empowered and resourced to fulfil its mandate. (Paragraph 151)

56. Transportation and transmission networks for hydrogen and electricity will need to be substantially improved and expanded. There is a need for sensible coordination in the design of hydrogen and electricity systems. Co-locating electrolysers and hydrogen-to-power generation with storage seems the most efficient option, but this will require significant electricity transmission infrastructure connecting storage sites to generation and to the grid. Hydrogen pipelines could connect storage to planned hydrogen industrial hubs. Without some assurance around how transmission networks will evolve, it will be hard for investors to make large-scale investment decisions into storage. (Paragraph 154)

57. There is an urgent need for key strategic decisions and investment into the transportation networks for both electricity and hydrogen. These network decisions should support the deployment of large-scale long-duration energy storage and a strategic energy reserve. These decisions should be communicated as part of the Strategic Spatial Energy Plan and delivered by a cross-departmental Ministerial Working Group, as currently exists for electricity network transmission infrastructure. (Paragraph 164)

58. We welcome the commitment to develop a Strategic Spatial Energy Plan, which is critical for long duration energy storage, but details remain unclear. We are unclear about the level of detail—for example, whether the Plan will be at the regional level or identify major facilities—as well as who will take responsibility for delivering on the plan once it has been developed by the Future System Operator. It is also unclear whether the plan will be given a statutory basis and how it will fit within the planning system. There is a risk that the Future System Operator develops a plan with substantial implications for national infrastructure and public expenditure, requiring coordinated action from many actors in the energy system, which the Government does not fully commit to, and so there is a lack of follow-through. 'Endorsement' of the plan may not be enough. (Paragraph 165)

59. The Strategic Spatial Energy Plan should include locations for long-duration energy storage and the supporting infrastructure. It must include provisions that support the Government's targets for hydrogen, and address the need for long-duration energy storage on the grid and a strategic reserve. It should be developed iteratively, and updated at regular intervals, with close collaboration between the FSO, Ofgem and the Government. (Paragraph 166)

60. The Future System Operator needs to be sufficiently empowered and resourced to develop a credible plan. As it does so, it must identify the key strategic, infrastructure and investment decisions that the plan entails. These decisions must then be made swiftly by the Government, which must then commit to ensure every actor in the system is working to deliver on them. Ofgem should endorse it in line with its Net Zero mandate. (Paragraph 167)

61. We urge the Government to publish timelines for developing the plan and details of what it will contain as soon as possible. It should consider whether a statutory basis for the plan is needed to ensure it is carried out. (Paragraph 168)

APPENDIX 1: LIST OF MEMBERS AND DECLARATIONS OF INTEREST

Members

Lord Berkeley (from 14 February 2024)
Lord Borwick
Baroness Brown of Cambridge (Chair)
Lord Drayson (from 31 January 2024)
Lord Lucas (from 31 January 2024)
Viscount Hanworth (until 31 January 2024)
Lord Holmes of Richmond MBE (until 31 January 2024)
Lord Krebs (until 31 January)
Baroness Neuberger
Baroness Neville-Jones
Baroness Northover
Lord Rees of Ludlow
Lord Sharkey (until 31 January 2024)
Viscount Stansgate
Lord Strasburger (from 31 January 2024)
Lord Wei
Baroness Willis of Summertown (from 31 January 2024)
Lord Winston (until 31 January 2024)
Baroness Young of Old Scone (from 31 January 2024)

Declaration of interest

Lord Borwick

No relevant interests declared

Baroness Brown of Cambridge

Shareholder in Rolls-Royce plc

Non-executive director of Ceres Power Holdings

Non-executive director of Ørsted

Chair of the Adaptation Committee of the Climate Change Committee

Viscount Hanworth (Member until 31 January 2024)

No relevant interests declared

Lord Drayson (Member from 31 January 2024)

No relevant interests declared

Lord Holmes (Member until 31 January 2024)

No relevant interests declared

Lord Krebs (Member until 31 January 2024)

No relevant interests declared

Lord Lucas (Member since 31 January 2024)

No relevant interests declared

Baroness Neuberger

No relevant interests declared

Baroness Neville-Jones

No relevant interests declared

Baroness Northover

Non-executive director, Pensana plc (sources and processes rare earths for magnets for batteries for electric vehicles and wind turbines)

Lord Rees of Ludlow

No relevant interests declared

Lord Sharkey (Member until 31 January 2024)

No relevant interests declared

Viscount Stansgate

President, Parliamentary and Scientific Committee

Trustee, Foundation for Science and Technology

Lord Strasburger (Member from 31 January 2024)

No relevant interests declared

Lord Wei

Adviser, Future Planet Capital (Investor in impactful technologies, some of which may include energy storage)

Adviser, Sweetbridge EMEA Ltd (a digital ledger technology company that works with industries including those that would work on energy systems)

Baroness Willis (Member from 31 January 2024)

No relevant interests declared

Lord Winston (Member until 31 January 2024)

Professor of Science and Society, Imperial College London

Baroness Young of Old Scone (Member from 31 January 2024)

Chair, Labour Climate and Environment Forum

A full list of Members' interests can be found in the Register of Lords Interests: https://members.parliament.uk/members/lords/interests/register-of-lords-interests

Specialist Advisor

Professor Keith Bell

Professor in Smart Grids, Department of Electronic and Electrical Engineering, University of Strathclyde (Chair sponsored by Scottish Power Energy Networks; funds primarily used for a postdoctoral research associate)

Member (part-time), Climate Change Committee (remunerated)

Co-investigator in research funded by the Electricity System Operator via Network Innovation Allowance (university remunerated for time)

Principal Investigator, Project led by the ESO, an extension of a project funded by the Strategic Innovation Fund (university remunerated for time)

Co-Investigator, UKRI Project on High Voltage Direct Current technology (university remunerated for time)

Member of the project board for work funded by the three onshore electricity transmission network owners and commissioned from some consultants, managed by The Institution of Engineering and Technology (university remunerated for time)

Recently engaged by Ofgem to review work it commissioned from consultants to assess the benefits of Locational Marginal Pricing in Britain (university remunerated for time)

Previous involvement in research funded through the university by National Grid, Scottish Power and SSE. In all cases, research outcomes have been published. (No remuneration)

Consultant, National Grid (personally remunerated)

Shareholdings in National Grid

APPENDIX 2: LIST OF WITNESSES

Evidence is published online at https://committees.parliament.uk/work/7872/longduration-energy-storage/publications/

Evidence received by the Committee is listed below in chronological order of oral evidence session and in alphabetical order. Those witnesses marked with ** gave both oral and written evidence. Those marked with * gave oral evidence and not submit any written evidence. All other witnesses submitted written evidence only.

Oral evidence in chronological order

*	Caroline Still, Senior Associate, Aurora Energy Research	QQ 1–8
*	Daniel Murrant, Networks and Energy Storage Practice Manager, Energy Systems Catapult	QQ 1–8
**	Professor Sir Peter Bruce, Physical Secretary and Vice-President, Royal Society	QQ 9–19
**	Timothy Armitage, Hydrogen Systems Consultant, Arup	QQ 20–30
**	Tom Lowe, Tom Lowe, Founder, Therman Storage UK	QQ 20–30
*	Professor Pam Thomas, CEO, Faraday Institution	QQ 20–30
*	David Surplus OBE, Co-founder, B9 Energy Storage Ltd	QQ 31–38
**	Jim Isherwood, Study Manager, io consulting	QQ 31–38
*	Matt Harper, Chief Commercial Officer, Invinity Energy Systems	QQ 31–38
*	David Gray CBE, Former Chair of the Gas and Electricity Markets Authority	QQ 39–45
*	Ita Kettleborough, Director, Energy Transitions Commission	QQ 39–45
**	Tim Lord, UK Head of Climate Change, HSBC	QQ 46–52
**	Alex Campbell, Director of Policy and Partnerships, Long Duration Energy Storage Council	QQ 46–52
*	Simon Virley CB FEI, Vice Chair and Head of Energy and Natural Resources, KPMG	QQ 46–52
*	Nick Winser CBE, Electricity Networks Commissioner, National Infrastructure Commission	QQ 53–59
**	Claire Dykta, Head of Markets, Electricity System Operator	QQ 53–59
*	Arnaud Reveillere, Head of Green Storage, Net-Zero Solutions, Geostock	QQ 60–67
*	Martin Scargill, Managing Director, Centrica Storage	QQ 60–67

*	Michael Liebreich, Chair and CEO, Liebreich Associates	QQ 68–82
**	Emily Bourne, Director of Energy Systems and Networks, Department for Energy Security and Net Zero	QQ 83–98
**	Stefanie Murphy, Co-Director of Hydrogen and Industrial Carbon Capture, Department for Energy Security and Net Zero	QQ 83–98
**	Professor Paul Monks, Chief Scientific Adviser, Department for Energy Security and Net Zero	QQ 83–98
*	Dr David Joffe, Head of Net Zero, Climate Change Committee	QQ 99–107
*	Owen Bellamy, Head of Power Sector, Climate Change Committee	QQ 99–107
*	Rachel Hay, Head of Energy Supply Decarbonisation and Resilience, Climate Change Committee	QQ 99–107
**	Emily Bourne, Director of Energy Systems and Networks, Department for Energy Security and Net Zero	QQ 108–125
	Stefanie Murphy, Co-Director of Hydrogen and Industrial Carbon Capture, Department for Energy Security and Net Zero	QQ 108–125
	Graham Stuart MP, Minister of State for Energy Security and Net Zero, Department for Energy Security and Net Zero	QQ 108–125

Alphabetical list of witnesses

*	Arup (QQ 20–30)	LES0031
	Association for Renewable Energy and Clean Technology (REA)	LES0021
*	Caroline Still, Senior Associate, Aurora Energy Research (QQ 1–8)	
*	David Surplus OBE, Co-founder, B9 Energy Storage Ltd (QQ 31–38)	
	British Geological Survey	LES0016
	British Hydropower Association	LES0038
*	David Gray CBE (QQ 39–45)	
	Centrica plc	LES0041
	Centrica Supplementary	LES0045
*	Martin Scargil, Managing Director, Centrica Storage Limited (QQ 60–67)	

*	Dr David Joffe, Head of Net Zero, Climate Change Committee (QQ 99–107)	
*	Owen Bellamy, Head of Power Sector, Climate Change Committee (QQ 99–107)	
*	Rachel Hay, Head of Energy Supply Decarbonisation and Resilience, Climate Change Committee (QQ 99–107)	
	Corre Energy	LES0030
*	Department for Energy Security and Net Zero (QQ 108–125)	LES0046
*	Department for Energy Security and Net Zero (QQ 108–125)	LES0015
	Drax Group	LES0013
	EDF	LES0026
*	Electricity System Operator (ESO) (QQ 53–59)	LES0044
	Energy Dome	LES0020
	Energy Storage Integration for Net Zero (ESI4NZ)	LES0042
*	Daniel Murrant, Networks and Energy Storage Practice Manager, Energy Systems Catapult (QQ 1–8)	
*	Ita Kettleborough, Director, Energy Transitions Commission (QQ 39–45)	
	Energy UK	LES0040
	Enoda	LES0012
	The Faraday Institution	
*	Professor Pam Thomas, CEO, Faraday Institution (QQ 20–30)	
*	Simon Virley CB FEI, Vice Chair and Head of Energy and Natural Resources, KPMG (QQ 46–52)	
	Flow Batteries Europe	LES0019
	Foresight Group LLP	LES0039
	Farm Energy	LES0018
	Future Cleantech Architects	LES0028
	Professor Seamus Garvey, University of Nottingham	LES0009
*	Arnaud Reveillere, Head of Green Storage, Net-Zero Solutions, Geostock (QQ 60–67)	
	Highview Power Enterprises	LES0011
*	Tim Lord, UK Head of Climate Change, HSBC (QQ 46–52)	
	Hydrostor	LES0037

*	Matt Harper, Chief Commercial Officer, Invinity Energy Systems (QQ 31–38)	
*	io consulting (QQ 31–38)	LES0043
	Michael Liebreich, Chair and CEO, Liebreich Associates (QQ 68–82)	
	Long Duration Energy Storage Council (LDES Council) (QQ 46–52)	LES0029
	MoltexFLEX Ltd	LES0027
	National Gas Transmission	LES0017
	National Grid ESO	LES0032
	Nick Winser CBE, Electricity Networks Commissioner, National Infrastructure Commission (QQ 53–59)	
	National Nuclear Laboratory (NNL)	LES0033
	Nuclear Industry Association (NIA)	LES0035
	Quarry Battery Company	LES0005
	RenewableUK	LES0036
	RheEnergise Ltd	LES0025
	Tony Roulstone, Lecturer, University of Cambridge, and Stan Zachary, Senior Lecturer, Heriot Watt and University of Edinburgh	LES0010
*	Royal Society (QQ 9–19)	LES0014
	SAVECAES: Sustainable, Affordable and Viable Compressed Air Energy Storage	LES0024
	Scottish Renewables	LES0022
	SSE	LES0003
	Statera Energy	LES0023
	Storelectric Ltd	LES0001
	Swanbarton Limited	LES0034
	Thermal Storage UK (QQ 20–30)	LES0004
*	Rt Hon Brian Wilson CBE	LES0008
	Ørsted	LES0006

APPENDIX 3: GLOSSARY

Technical term	Definition
Black start	Black start is the process of restarting the grid after a partial or total shutdown, which would require isolated facilities being restarted and gradually connected to each other to form an interconnected electricity system again. This requires individual facilities in strategic locations, which are capable of switching themselves back on in case of a power outage, which the National Grid can procure "black start" services from to restart the grid if needed.
Curtailment	Curtailment in renewable energy is the deliberate reduction in output below what could have been produced in order to balance energy supply and demand or due to transmission constraints. Wind generation in the UK is often curtailed.
Decarbonisation	Reduction or elimination of carbon dioxide emissions from a process, such as manufacturing or energy production.
Electrification	Shifting energy demand towards electricity—for example, electric cars replacing fossil fuel cars, or heat pumps replacing gas boilers
Electrolysis	The process of using electrical currents to drive chemical reactions—particularly the splitting of water into hydrogen and oxygen. Machines that do this are called electrolysers.
Explicit trading	Explicit auction is when the transmission capacity on an interconnector is auctioned to the market separately and independently from the marketplaces where electrical energy is auctioned. Since the UK has left the EU's electricity market, it must bid for transmission capacity in this way, and it has been argued that this is a less efficient form of trading, as traders have to bid for capacity before they know the price of electricity that will be sold.[247]
Inertia	Inertia in power systems is currently provided by rotating turbines in thermal electricity generators. If there is a sudden change in system frequency, such as a power plant outage, the turbines keep spinning due to their inertia, which slows down the change in frequency of electricity on the grid while stability is restored, so it is important for controlling the frequency of the alternating electrical current. Renewables do not have the same property of spinning turbines that rotate in sync with the electricity frequency.
Intermittency	In renewable electricity, this refers to electricity generation that is not continuous but subject to periodic stopping. Wind and solar are both intermittent.

247 Frontier economics, 'Brexit and interconnectors: a £45m problem?': https://www.frontier-economics.com/uk/en/news-and-insights/articles/article-i8192-brexit-and-interconnectors-a-45m-problem/ [accessed 10 January 2024]

Technical term	Definition
Load factor	The load factor is the effective percentage of theoretical maximum generating capacity that is used over a given period of time. A power facility with a maximum, or nameplate capacity of 100 MW might only generate 80 MWh in an hour if it is not always operating at full capacity, so the load factor would be 80%.
No-regrets	No-regret actions are cost-effective now and under a range of future climate scenarios and do not involve hard trade-offs with other policy objectives.[248] A no-regrets level of investment in hydrogen storage would be an amount of infrastructure which is useful under a range of different assumptions about what the future energy mix and price of renewables would be, which can be determined through modelling.
Phase-change materials	In thermal storage, phase-change materials are materials that can absorb or release heat by changing phase—for example, from solid to liquid (absorbing heat as they melt).
Reactive power	Reactive power services allow the grid to maintain safe voltages (the voltage is the amount of power transferred by a given current of electricity), and generators or other electricity system assets that can help maintain voltage control across the network are said to absorb or generate reactive power.
Unabated	"Unabated" use of fossil fuels colloquially refers to fossil fuels that are used without any carbon capture and storage methods to reduce their emissions.

248 Climate change, 'Examples of 'no-regret', 'low-regret' and 'win-win' adaptation actions' (November 2012): https://www.climatexchange.org.uk/research/projects/examples-of-no-regret-low-regret-and-win-win-adaptation-actions/ [accessed 10 January 2024]