



Science and Technology Committee

Corrected oral evidence: Long-duration energy storage

Tuesday 12 September 2023

10.15 am

[Watch the meeting](#)

Members present: Baroness Brown of Cambridge (The Chair); Lord Borwick; Lord Holmes of Richmond; Lord Krebs; Baroness Neuberger; Baroness Neville-Jones; Baroness Northover; Lord Rees of Ludlow; Lord Sharkey; Viscount Stansgate; Lord Wei.

Evidence Session No. 1

Heard in Public

Questions 1 – 8

Witnesses

Caroline Still, Senior Associate, Aurora Energy Research; Daniel Murrant, Networks and Energy Storage Practice Manager, Energy Systems Catapult.

USE OF THE TRANSCRIPT

This is a corrected transcript of evidence taken in public and webcast on www.parliamentlive.tv.

Examination of witnesses

Caroline Still and Daniel Murrant.

Q1 The Chair: Welcome to the first session of our new inquiry into long-duration energy storage. We are very pleased to welcome our first two witnesses: Caroline Still, a senior associate at Aurora Energy Research, and Daniel Murrant, the networks and energy storage practice manager for Energy Systems Catapult.

We are recording this session and it will appear on parliamentlive.tv. There will be a transcript of what you say, which will be sent to you for minor corrections shortly afterwards. If there is anything that you feel you did not get the chance to say, or if there is data that you think it would be helpful for us to have and that you would like to submit to us as formal evidence after the session, we would be delighted to receive it.

Before I start the questioning, I declare my interests as a non-executive director of Ørsted and of Ceres Power. I also hold a significant number of shares in Rolls-Royce, the aero-engine and energy company.

Could you outline the role that long-duration energy storage would need to play in a fully decarbonised grid and indicate how long-duration storage is defined?

Caroline Still: Thank you very much for having me here today. I beg your pardon for my throaty voice.

First, it is useful to unpack the definition of long-duration storage to frame the discussion that we will have. Long-duration storage is quite simply defined as energy or electricity storage technology that can respond to supply and demand peaks caused by daily peaks, weather events and seasonal variations, providing energy for over four hours of duration at a time.

We find it less helpful to limit the definition to a minimum capacity, because quite a few nascent long-duration storage technologies are not yet at capacities exceeding 50 megawatts to 100 megawatts, so limiting the definition to over 100 megawatts would prevent these technologies from partaking in any meaningful way to the grid. Even though technologies of over 100 megawatts will obviously have a more significant impact on decarbonisation goals, we feel that every little bit helps at this point. Therefore, the definition should be all-encompassing.

On the role of long-duration storage, it is useful to outline four key needs of decarbonising the grid and how long-duration storage is well positioned to address those needs. They include firm capacity provision, flexible capacity provision, the alleviation of grid constraints, and grid stability provision to provide energy security. I will unpack each of those a little more.

Firm capacity is what we most commonly associate with the need that long-duration storage can fulfil. That is: dispatchable capacity that can provide generation during periods of peak demand. For long-duration

storage, that simply means the ability to shift generation from periods of excess to periods of need by storing it and dispatching it later. That can happen in three different demand profiles: daily, weekly and seasonal. Daily demand profiles are what we most commonly associate with short-duration storage; it is associated with the change of energy demand over the day. We expect that to get more peaky over the forecast period while we decarbonise, due to the electrification of things like heating and transport.

Weekly demand profiles are caused by weather variations, such as periods of extreme wind for several days at a time that are caused by a storm, for example, or periods of no wind for several days at time. Long-duration storage can alleviate that by absorbing the excess over several days and dispatching it at a later period. That is especially important in a grid such as the UK's, which is very heavily reliant on wind power. Long-duration storage is an important technology that can provide firm capacity during periods of wind drought, as it were.

Then we have seasonal variation—the excess generation during the summer and the excess demand during the winter—which, as we decarbonise, will again become more extreme due to the electrification of heating in the winter and the huge amount of solar generation in the summer. Some long-duration storage technologies, such as power-to-gas—the conversion of electricity to hydrogen and then back to electricity again—can be used to help to smooth out the seasonal variation, although there is a debate as to whether that is the best use of the valuable green hydrogen produced, which I understand is something that the Select Committee would like to discuss in more detail later.

Flexible capacity is the second need of the grid that long-duration storage is quite well positioned to address. That is the ability to generate capacity to ramp up and ramp down very quickly. It is becoming more important. 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. Having more technologies on the system that can respond in a matter of milliseconds to balance the grid is becoming increasingly important.

I will put some numbers to that. We expect the need for ramping to double between 2030 and 2050, according to our net zero forecasts. That takes it to about 26 gigawatts per hour. To put that number into context, that is about 20% to 25% of the current installed capacity in the grid. So, within an hour, about a fifth of the current grid would have to turn on, in order to balance the grid. That just highlights how the need of ramping capacity is particularly important.

Network constraint resolution is the third need which long-duration storage is well positioned to help to alleviate. It is specifically related to the separation of generation and demand. With the huge number of renewables coming on to the system, generation of power is often not located close to demand centres. That is the case in the UK; a huge amount of wind generation is coming online in Scotland, for example, but a lot of the demand is located in the south near London.

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 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. Long-duration storage can of course absorb that excess renewable energy, rather than it being curtailed, and dispatch it later when the transmission lines are not at capacity.

It is important to note that long-duration storage should not be considered a replacement for grid buildout. If that were the case, we would get long-duration storage technologies perpetually at full capacity in the north and never able to dispatch because the transmissions lines would be full, having not been built out at the required pace. Instead, we feel that the grid buildout is still required to provide a locational distribution of power generated across the UK. Long-duration storage can complement that process by providing the redistribution of energy over time in order to maximise utilisation of the transition capacity buildout most effectively.

The last need of a low-carbon grid is that of grid stability and security. Synchronous generation includes generators that have a turning mass, which provides a sense of inertia to the system. 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. Long-duration storage technologies can provide some, if not many, of those different ancillary services to provide security to the grid. That includes inertia, reactive power, frequency control and black start.

That covers the four key areas in which long-duration storage is well positioned and which define its role.

Q2 The Chair: Thank you. That seems pretty comprehensive. Daniel, do you have anything you would like to add to that? If not, I will also ask you the next question.

We would be very interested to know what the key considerations are in estimating how much long-duration energy storage we are likely to need. Do you have a figure from your work at Energy Systems Catapult for the range you would estimate for the storage requirements for our fully decarbonised grid in 2035 and by the time we get to 2050? If there is anything you want to add to what Caroline has said, please do.

Daniel Murrant: On the first question, I agree that long-duration energy storage is typically considered to be greater than four hours. Actually, to me, that hides a lot of the detail. As Caroline was saying, there are lots of different services and needs within that. Typically, I think of storage of up to 200 hours as medium-duration energy storage. There, you are perhaps providing within-day or inter-day storage flexibility.

Then there is long-duration energy storage. There, we are looking at seasonal storage. The needs and roles played by those two categories are quite different, so we should look at them differently. Following on from that, there will be different types and levels of support.

I absolutely agree with the point that was made about constraint management. Yes, long-duration storage can help with that. We just have to be mindful of how severe that constraint is. If it is a very severe constraint, sometimes the issue is that you absorb the electrical energy and you cannot get it back on to the network because the constraint is so bad. Multi-vector storage—switching to hydrogen or another vector—is also beneficial.

On the second question, the amount of longer-duration energy storage needed is dependent on how flexible the rest of the generation in the system is. If there are lots of renewables, as we expect, that is very good—low-carbon is great and fairly cheap—but they are inflexible, so we need the back-up firm capacity to be able to manage those periods of low wind and low solar to provide energy security.

In the analysis that we have done, the number really depends on the mix of generation technologies; having more nuclear in the system, having more gas for carbon capture and storage, for example, provides flexibility. We are quite clear that in that long-duration category we are very much talking about tens of terawatt hours. Different studies will argue over whether it is 20 or 100. Frankly, it does not really matter. The point is that we will need tens of terawatt hours of low-carbon energy storage for long duration. Looking at what we have as low carbon long duration energy storage at the moment, it is fractions of a terawatt hour. Whether it is 20 or 100, it does not matter; we need a rapid acceleration in deployment of that long-duration storage. We can argue about the exact number later on.

The Chair: By 2035, we will not have built much more nuclear, so we have a pretty good idea of what a zero-carbon grid will need to look like.

Daniel Murrant: Certainly we will not have much more nuclear in the system. Whether we will have gas with CCUS or bioenergy, from our analysis it changes per scenario; lowish tens of terawatt hours, 20 terawatt hours perhaps of long duration energy storage, again very much scenario-specific.

Medium-duration energy storage is very important. Again, it plays a bridging role. We all know that weather varies. We talk a lot about long periods where there is no wind, but typically there could be some wind for a couple of days and then not for the next couple of days. Demand, again, varies—it can be a slightly colder day, a slightly warmer day. Having that kind of storage to be able to provide flexibility over a period of days to a week is where we see medium-duration energy storage.

I can give numbers from our scenarios. This is very much scenario-dependent, but we are talking about maybe 30 gigawatts, which corresponds into hundreds of gigawatt hours. However, there is a research gap in the interaction between medium and long-duration

energy storage. When you consider hydrogen storage, plus hydrogen turbines or hydrogen fuel cells, as a medium-duration technology, it tends not to add up because of the efficiency and the amount that you are cycling. If you have to do it for that seasonal long-duration storage anyway, and you have some of that capacity built into the system, the numbers may look a lot different.

I do not know, is the honest answer, but that is an area where there is a gap. There is definitely a role for pumped hydro, compressed air, liquid air—all medium-duration technologies—but the scale of it, and how it interacts with seasonal storage, is something to explore further.

The Chair: Thank you.

Q3 Lord Sharkey: Following on from that, the question is how sensitive the amount of long-duration energy storage needed is to assumptions about the balance of supply and demand on the grid. For example, is it possible to significantly reduce the amount of storage needed with nuclear power, carbon capture and storage, demand-side management, or interconnectors?

Daniel Murrant: You can reduce it, but I do not think you can move away from that large number. There are a couple of reasons. With nuclear, there are still question marks around how flexible it is. Newer nuclear technologies which have been developed are more flexible, but they are unlikely to be dispatchable like say a gas turbine.

In terms of carbon capture and storage with gas—I mentioned this earlier—this comes down to the capture rate. How much of that carbon can you actually capture? It is not 100%. Our analysis shows that although carbon capture and storage is very important for decarbonising the energy system, it is not entirely carbon-free, so you really have to prioritise where you use it. In our models, we see it being used predominantly for industrial decarbonisation. That is where there are fewer options. If you are doing that, you are taking away one of the main flexible sources of generation.

Even if you do have gas for CCUS, you still need large amounts of storage—it is just that it is natural gas-based storage. However you cut it, storage is very important. It is just the type and role that it plays.

Caroline Still: I second that. With nuclear specifically, at the moment, any sort of flexible nuclear is not proven at scale. Decreasing or increasing the amount of nuclear is obviously valuable to the system in many other ways but it does not replace the role that long-duration storage plays in terms of firm capacity, flexibility capacity and management of grid constraints.

I agree with what has been said about carbon capture and storage. The system infrastructure and storage required to deploy carbon capture and storage at the scale required to achieve net zero by 2035 is significant and costly. If we are looking at technologies that are scalable and have a technology readiness level to deploy as of today, long-duration storage is

one of the better technologies available in comparison to carbon capture and storage in order to meet that 2035 goal.

That is not to say that carbon capture and storage will not be needed as we approach 2050 and economy-wide decarbonisation. It is absolutely a technology that we should continue to focus on, as the Government currently are. However, I do not think it is a replacement for long-duration storage.

Additionally, carbon capture and storage can provide that flexible generation when there is a shortfall in generation—so when there is a lot of demand and insufficient supply—but it cannot absorb the excess generation that we expect to have with a huge amount of wind and renewables on the system. If we are not making best use of the excess generation that is being produced, we risk the efficiency and the cost of our system.

Things like DSR—demand-side response—and interconnectors, more broadly categorised as demand-side flexibility, can absolutely reduce the amount of long duration storage required by the system.

Lord Sharkey: Significantly or not?

Caroline Still: Not terribly significantly according to our analysis, but, again, as Daniel highlighted, it really depends on the scenario that you are looking at and the mix of technologies that you have on the system. Some preliminary analysis that we have done showed that doubling the DSR capacity on our net zero scenario by 2050 to 19 gigawatts, as opposed to 9.5 gigawatts, reduced the total storage requirements by about 3 gigawatts to 5 gigawatts. So it is not a one-to-one replacement, but it helps to alleviate some of that constraint. The difficulty with DSR is incentivising it and automating it enough to ensure energy security and security of supply, which is also receiving a lot of focus now.

I do not feel, and I think Daniel is also saying that he does not feel, that one specific solution is better than another. Definitely a combination of all of them will be required to meet that net zero goal as quickly as possible.

On the pace that we need to meet that goal by 2025 and the cost, long-duration and medium-duration storage absolutely need to be part of the mix.

Lord Sharkey: Thank you.

The Chair: You talked a bit about the transmission system and, eventually, the lack of capacity in it. Where is the balance between improving and investing in the transmission system and investing in long-term storage? Does that give us a challenge with interconnectors, because do we not need the power to arrive where we want it, rather than to arrive up in Scotland where we sometimes have far too much locally?

Daniel Murrant: There is a quite a bit to unpack there. I think we would say that both are needed. I know that you are talking about balance, but we will need network reinforcement, transmission, distribution and lots of storage. Exactly what that balance is, is unknown and something that we

are starting to look at. It is not just the amount of storage; it is where it is, and the vector. that is very important as well. We simply do not have enough information on that.

On the role of interconnectors, again, I agree with Caroline that they are very important, but, on the exact role of long-duration energy storage, you have to be very conscious that European weather cycles are broadly similar to ours and there are potentially also political issues. There is definitely a role for interconnectors, but we need to understand how that fits into the system. You used the example of interconnectors coming into Scotland, but that is more about having flexibility where you need it when you need it.

I do not want to move on to another subject, but this is where the current discussion on locational pricing comes in. This is where you start to stray into that. I will not take us off down that route, but that is one option at least for beginning to bring the locational element in so that you get the flexibility where you need it. Of course, you then have to be aware of geographical constraints on some of your storage; pumped hydrogen needs valleys, hydrogen needs caverns, et cetera.

The Chair: Sorry, did you say locational pricing?

Daniel Murrant: Yes.

The Chair: So encouraging people to move their factories to Scotland, or wherever, because electricity is cheaper there.

Daniel Murrant: I am not a policy expert, but essentially at the moment we have a single wholesale price, which you can change so that you have your generation and your flexibility where it is needed, rather than where it is perhaps convenient, for other reasons, to provide it.

Caroline Still: I agree with Daniel on that, but the conversation about locational pricing is acting as a level of uncertainty in the medium and long-duration storage transaction space. The uncertainty of underpinning revenue streams is driving away investment rather than attracting it, and there is uncertainty about whether these prices or network charges will necessarily change. If we bring pace back into the mix again, the current system is probably better suited to bringing long-duration storage on more quickly than not and to meeting the decarbonisation goals.

On the mix of grid buildout versus medium and long-duration storage, I agree with Daniel that that can be modelled in a million different ways, and we could have many conversations about that. At the end of the day, it really comes down to where the subsidisation is going. If we take a black-box approach, something will be subsidised in some way to support that deployment, whether it is the grid buildout, a cap and floor mechanism for long-duration storage, or a combination of both. Ultimately, both routes need support in some way to accelerate them.

The Chair: It seems that we need some clarity very soon, given that 2035 is not very far away.

Q4 **Lord Borwick:** When it comes to specific technologies, can you outline

the role of batteries in this? A long time ago, everyone said that car batteries, in their last stage below 70% capacity, would become big storage.

Caroline Still: Absolutely, yes.

The Chair: Is that still realistic, or do you not think that will happen?

Caroline Still: We would categorise car batteries more as a form of demand-side flexibility, something that can provide a reduction in peak demand in the grid through smart charging. The potential of that is limited by how automatable it is and how much that can be incentivised.

I understood your question initially to be about the role of electro-chemical storage in long-duration and medium-duration storage—

Lord Borwick: That too.

Caroline Still:—the movement of ions and its ability to generate electricity. There, we are really looking at the role of lithium-ion batteries and redox flow batteries in storage and how that technology is better than others.

The major benefit of that technology is, of course, that it is locationally independent. Its electrochemical nature means that it has a particularly high efficiency—75% up to 90% or 95%, depending on the technology. That is quite high in the realm of medium to long-duration storage. It is also particularly scalable in modular form, so you can achieve pretty good capacities with it, and it has incredibly fast response times—in the order of milliseconds. These all fulfil some of the needs that we spoke of earlier with flexible capacity and achieving an efficient transfer of that energy, storing it and dispatching it later.

The downside, of course, is that a lot of those electrochemical technologies still have very high costs for longer-duration storage versions and are still relatively nascent. Lithium ion as a technology is quite advanced, but not for eight hours-plus, mainly due to the significant cost barriers that prevent it being deployed and driving down costs in a meaningful way.

Additionally, all electrochemical technologies are prone to normal degradation, meaning that, over time, the battery degrades, as you mentioned. That is the same as shorter-duration storage technologies, so it would have to be factored into the financials.

Finally, electrochemical technologies rely heavily on critical minerals such as lithium, so relying entirely on that for medium and long-duration storage would expose the UK to more supply-chain risk, too. There are benefits as well as drawbacks to electrochemical technology, which means that it should definitely be considered a part of the mix, depending on which technologies manage to overcome those cost hurdles, but it would not be the only technology that is needed. However, combined with pumped hydro storage as well as the vector storage that you spoke of—power to gas—it proves to be a robust addition.

Daniel Murrant: I absolutely agree. There is scale and duration to think about, putting flow batteries to one side, which are a slightly different chemistry and certainly do fit into medium-duration storage, with lithium-ion and lead acid, which are typical batteries, you are typically talking about a duration of two to four hours. Typically, at the moment, most of the ones that we have are even more like one or two hours, albeit that that is market-driven.

Again, a car battery is about 40 kilowatt hours. Obviously, you may have millions of them, but you are still only just getting into the gigawatt range, and typically the duration is only one or two hours, your low-hundred gigawatt hours. With some of this, we are talking ultimately about requiring terawatt hours.

Is there a role for them? Absolutely, but to me it is largely on the shorter-duration energy storage side, with the exception of redox flow batteries, because their duration is longer—maybe 10 hours, or a bit more. That duration helps you to get that scale-up of energy volume, which is obviously useful.

Lord Borwick: You mentioned the efficiency being 75% and higher for batteries. What is the equivalent figure for hydrogen?

Caroline Still: It depends on how we look at it, but that is a great question. If we are talking about hydrogen as a form of storage, the full cycle is using electricity to power electrolysis to make hydrogen, storing that hydrogen and using it later to make electricity again through a turbine or a fuel cell. The full round-trip efficiency is below 50%, somewhere around 30%, because you have losses in the electrolyser and in the combustion, again—the same sort of losses that we see at the moment in CCGTs or gas peakers. So the round-trip efficiency is significantly lower than you would get from electrochemical, but, as Daniel highlighted, electrochemical does not reach the duration that hydrogen does. Technically, you could store the hydrogen indefinitely, but electrochemical does not have that potential.

Lord Borwick: You did not mention compressing the hydrogen. That is one of the big costs, is it not?

Caroline Still: Absolutely. On cost, infrastructure and transport, there is a lot more to unpack regarding hydrogen as a form of storage, necessarily.

Daniel Murrant: I absolutely agree. This comes down to the fact that the roles they are playing are not like-for-like comparisons. Again, for batteries, DSR and shorter-duration storage, you would not use hydrogen; that just does not make sense in terms of efficiency. Then you have medium-duration storage—we have already named these technologies, but they include pumped hydro, compressed air and liquid air. There are some variations of them that are beginning to come online, including pumped hydro with a denser liquid. That is still very much in the early stages, but it essentially reduces the size of the area you need. There are different versions of compressed air, including different thermodynamic properties that will change how they can be used. There

is lots of good work going on there, although I have definitely missed some.

My message is that, until the point of seasonal storage, there are options; there is probably a portfolio approach. However, when you get to very seasonal storage, the options become limited. It will have to be gas-based, because you need scale and the ability to store it. Obviously, we want low-carbon, so hydrogen appears to be the front runner. There are other options—you could use natural gas—but you return to the reliance on carbon capture. Again, ammonia is an option, but it is really a hydrogen carrier. Other very novel options are still being developed, but they are very much in the earlier stages.

Up to that seasonal stuff, you have loads of options, but, once you get to the seasonal stuff, your options reduce. Then there is the question: if you have that seasonal storage, how does it play back into the medium-duration?

The Chair: That takes us to Baroness Neville-Jones's question.

Q5 Baroness Neville-Jones: Thank you, Chair. I have no interests to declare.

In the light of what you said, do you feel that, in current policy, enough of a distinction is made between the short and medium-duration storage, which smooth things out over short periods, and the longer-term storage that is needed much more for the monthly basis. Are we getting our definitions and analysis right?

Caroline Still: I am happy to speak to the short and medium-duration in a little more detail. Various revenue streams can be attributed to one and not the other. For example, shorter-duration has access to dynamic containment, whereas longer-duration has access to reactive power services.

Even so, the only material revenue stream that is very different is access to capacity market contracts and the proportion of the capacity market that longer-duration storage technologies have. Their better derating factors mean that the capacity market can make up to 25% of their gross margin forecast stack, according to our analysis of a pumped hydro asset. However, for a shorter-duration asset of about two hours, we are looking at closer to 5%. By and large, both short-duration and medium-duration storage technologies rely most heavily on value derived from energy trading—charging and dispatching in the wholesale market and balancing mechanism.

For the longer-duration assets, this makes up about 60% of their gross margin stack, with a lot of it coming from the capacity market as well. However, the shorter-duration assets rely mostly on energy trading, which is essentially the merchant behaviour of the battery, and it makes up to 80% to 90% of their gross margin stack.

Longer-duration technologies are capable of capturing more value from energy trading due to their longer duration, meaning that they can

charge for longer periods at higher prices and can access periods that shorter-duration technologies might not have access to. However, I will highlight that this relationship has a diminishing return as duration increases. The longer the duration of the asset, the more money it can make in energy trading, but, incrementally, it will make less and less money the longer the duration of the asset. That means that the upside of having longer-duration or medium-duration assets in energy trading is not sufficient to offset the cost of that asset or the increased capex or lead time of developing an asset like that. Therefore, the policy is not significantly different enough to incentivise investment into long-duration.

We have seen quite a lot of activity in the shorter-duration market, with a lot of transactions in the last couple of years and a lot of batteries set to come online over the next five years in line with the capacity market. That highlights that the merchant business model of those assets is indeed viable, but we are not seeing the same level of activity in long-duration storage. We are seeing a lot of interest, but also a lot of hesitation because of the cost barriers at the moment, because the merchant behaviour in energy trading is not significant enough.

I will highlight two mechanisms that could de-risk the medium-duration behaviour. The first is a revenue floor to help to provide a minimum that banks can lend against. This is in the form of something like the cap and floor mechanism, as mentioned in REMA and as was used by interconnectors. That would definitely help to provide a floor and to de-risk the uncertainty over where the locational value is of the assets and whether various revenue streams might change as pricing and network mechanisms change over the next couple of years.

The second mechanism that could benefit long-duration or medium-duration storage would be one that better incentivises the additional services that long-duration storage can provide to the grid. That would quantify, most importantly, the locational value of long-duration storage, other than just through the balancing mechanism, as well as the ancillary services that it can provide in a more certain way—namely, reactive power and inertia in a longer-term certain price forecast. We feel that this floor would de-risk debt, and the other mechanisms could help to provide an additional upside to attract the equity market, possibly unlocking more investment in that space, and to provide enough of a difference between the short-duration and medium-duration assets.

Daniel is probably in a better position to speak to longer-duration policy, but I completely agree on the excess generation on a seasonal basis: if we have a huge number of renewables on the system, we will definitely have seasons when we have a lot of excess generations and seasons when we have a shortfall. Hydrogen has clearly been highlighted as one of the best technologies to capture that energy in the form of another vector to use later. However, I would question whether the use of that very valuable green hydrogen is best suited to the power sector or to other parts of the economy that are equally difficult or more difficult to decarbonise and that do not have alternatives, including the high-temperature industry and heavy-duty transport.

At Aurora, we feel that hydrogen will absolutely be used in power, but to a much lesser extent compared to how much of it will be used in the high-temperature industry and heavy-duty transport—approximately 5% to 10% of our total hydrogen demand estimate by 2050. Absorbing that electricity, turning it into hydrogen and storing it—and incentivising that in policy—is a great way to minimise the losses of our grid and to maximise the efficiency of the system. Where we then use that hydrogen should be considered a separate topic, rather than always considering it as part of a round loop of electricity to hydrogen and back to electricity. With electricity to hydrogen, it is best to use that hydrogen in a merit-based order of most effectiveness.

Daniel Murrant: I absolutely agree that there are multiple roles for hydrogen. We probably disagree slightly on the numbers, but that very much comes down to scenario assumptions. There are definitely multiple roles.

On policies for the support of storage, we have been doing some work with SMEs in the storage and flexibility space. That includes a range of different technologies, but they are all start-ups trying to get into the market. The point that is coming across very clearly from them all is that one of their key barriers is that there is still too much focus on lithium ion. That is not to say that lithium ion is not important, but when they are trying to find markets and revenue streams, a lot of them are almost subconsciously set-up for lithium ion. So a better definition of storage, when you have short, medium and long-duration, helps, but it will not be a silver bullet.

Planning reform, again, very much depends on the technology, but there are some battery technologies that, in the planning process, are just classed as energy generation, so they could be treated the same as a wind farm or solar wind, although they are clearly very different.

I know there is a strategic co-ordinated approach to planning in the electricity system being discussed at the moment, but it has to be multi-vectored. When you look at the networks that we need in the future, and the needs they are meeting, where are the synergies between them so that we can share risk and value? It should mean that in the future the system is more co-ordinated and maximises benefit.

The final point is about the strategic reserve support for this very long stuff. Another way to define storage is how much it cycles. The shorter things discharge daily, perhaps multiples times per day. Medium-duration discharges slightly less. Very long seasonal storage may not discharge for the whole summer. How you make money is how you cycle, when you sell your energy. For that very long stuff, we think there will be some need for some kind of strategic reserve, and there will need to be policy support in place to help that.

Baroness Neville-Jones: Do you reckon that the problem you have identified is a gap in government thinking, or a gap in market discussion? How do you stimulate the incentives?

Daniel Murrant: I think it starts with government. I know that is easy to say, but direction needs to be set. As Caroline rightly said, we need long-duration storage and rapidly; we are nowhere near what we need for the 2035 target. I am not a policy expert, but once you have that kind of direction, that may allow market conversations to come in as well—so there may be a market element to it. I do think that part of it will be a mechanism that ensures that capacity is there.

Caroline Still: That is an interesting comment about a sort of capacity market, except one for strategic reserve instead. Additionally, the low-carbon hydrogen business model that is currently in discussion is another way of financially incentivising that storage. As you said, it does not make economic sense to convert this excess electricity at a very low price into hydrogen and pay for that storage. Is the price that I can sell hydrogen for at a later stage high enough that I can make a sufficient return on that length of storage? The work that has been done on understanding where the hydrogen price should be explored separately to LDES, whether we should subsidise the hydrogen price or the production of hydrogen, and how hydrogen can be incorporated in the wider economy, whether it be in electricity or another form, is a good way of incentivising that financially.

Baroness Neville-Jones: Thank you, that is very helpful.

Lord Sharkey: Or using, perhaps, contracts for difference.

Caroline Still: Yes, for something like an electrolyser. Again, that is using a contract for difference to ensure that the hydrogen can be sold at a market price that is regulated by the Government, but ensuring that the electrolyser does not lose money making it.

Q6 **Baroness Northover:** You have implicitly addressed some of these points here. If I can ask you to do this explicitly, as you will know, and as Baroness Brown has mentioned, the Government have committed themselves to a target of a fully decarbonised electricity grid by 2035. The Opposition's target is 2030. Explicitly, are the Government's actions and the Opposition's plans on track to meet this? If they are not, how feasible are those targets?

Daniel Murrant: The short answer, I believe, is no. We should praise ambition: there has been good ambition and good targets right across the energy system. However, we are not on target to meet a lot of them. We have already talked about the need for long-duration energy storage. We have a very small amount compared to what we are going to need.

We are fast running out of time, but there is still time. As has already been said, rapid action is needed. As of today, although there are very good targets, we are just not on course to meet them. There is also a supply chain risk here. The UK was a leader in meeting climate change targets and decarbonising. There is a risk that as other countries catch us up and perhaps overtake us, that shifts the supply chain, which makes it harder for us to catch up again. There is great ambition, but delivery and execution are where we need to improve.

Caroline Still: I would agree with that. As we have discussed, there are obviously several parts to net zero and varying different combinations of technologies that can be used to reach the same goal. The one key thing that is quite clear is that, in terms of technologies that are scalable and slightly more cost-effective and can provide firm and flexible capacity in time for 2035—or, according to the Opposition, 2030—long and medium-duration storage technologies are one of the only low-carbon options available for that. Alternative low-carbon options, such as carbon capture and storage, or using hydrogen in peakers or in CCGTs, require far more infrastructure build-out and are possibly more costly.

Do I think that not achieving the long-duration storage would be fatal to the target? There are possible other routes, but it would be more of a challenge, and certainly more costly to the system as a whole, if long-duration storage was not incentivised. As I mentioned earlier, I do feel that these other technologies have an important role in the system, as early as 2035, but certainly after that if we are looking at decarbonising the system as a whole, not just power. We will definitely rely on hydrogen and carbon capture storage in some form or another. In terms of meeting that 2035 target, long-duration storage is probably the one that is most ready to be deployed at scale.

Daniel Murrant: You have touched on this. If we get to 2035 and we have the renewables on the system—so we have hit those targets; we have the 50 gigawatts of offshore wind and the heat pumps—and we have a system that requires lots and lots of flexibility but we do not have it, what will probably happen—obviously we will not have blackouts—is that we fall back on our gas turbines.

The risk there is technology lock-in. So not only will we have missed the 2030 or the 2035 target, but we will also have this fleet of CCGTs, which we have had to maintain to ensure energy security, that are going out to perhaps 2040 and onwards. I absolutely agree that it is missing the original targets, but if you miss them, the potential default locks you in even further.

The Chair: Do you both feel that between now and 2035 we need at least 10 terawatt hours of long-duration energy storage that we do not have at the moment?

Daniel Murrant: From my point of view, yes, you absolutely need that. There are two things: net zero and energy security. Net zero is absolutely critical; for that, we will need the terawatt hours of low carbon long duration energy storage. From the energy security point of view, there is the option of always just relying on the CCGT, but then you are not meeting net zero and you miss your target. I am conscious that I am focusing a lot on the very long stuff, but you absolutely need the medium stuff as well. So, yes, is the short answer.

The Chair: Given that we import most of our gas, that does not really give us energy security, does it?

Caroline Still: We did a market-sizing exercise in which we looked at the scale of imbalance in a net zero scenario: how much shortfall and how

much excess there is from just intermittent renewable generation and low-carbon generation such as nuclear. Long-duration storage could possibly fill that gap, which is the size of 46 gigawatts, moving approximately 57 terawatt hours of energy by 2035. But that really is a maximum market size, not the role that long-duration storage should or can play.

In our net zero scenario, where we have all the other technologies in the mix and there is more of a synergy between the technologies acting, we see the value for storage being closer to 20 to 25 gigawatts for storage as a whole, with long-duration storage possibly making up to half of that. Again, when I say long-duration storage, I am specifically talking about medium and long-duration storage.

In terms of the tens of terawatt hours that could be provided by something like very long-duration storage—seasonal storage—that is on the upper end of our estimates. We see that hydrogen in power will account for about 8 terawatt hours of generation by 2050 in our net zero scenario. That is approximately 1.5% of total generation by 2050. It is really quite a small part, but an important part, because what we are saying is that there is no other technology on the system that can provide that power at peak demand points, because the CCGTs will have been decommissioned.

However, we have looked at a more extreme scenario, as you just mentioned, where we have no gas in the system by 2050—when I say no gas in the system, I mean not just power but heating, industry and so on—and we import no hydrogen. This is a system where all hydrogen is domestically produced through electrolyzers. In this scenario, which is obviously very extreme, we are looking at about 45 gigawatts of electrolyzers, 220 gigawatts of solar and wind generation capacity, and 30 terawatt hours of that hydrogen produced being used again in the power system again. So tens of terawatt hours is in the realm of scenarios that we have modelled, but that is a particularly extreme scenario, so it is at the edge of what we would consider feasible in terms of the numbers that I have just quoted.

Q7 **Baroness Neuberger:** I have no interest to declare. I think you have answered most of my question. You have talked in great detail about the long storage as opposed to the short or medium. How well are we doing in the UK? You do not sound terribly optimistic. Can you say something about that?

Caroline Still: I would not say I am not optimistic at all. I am very excited to be positioning my career in decarbonisation in the UK, with the UK being a world leader in decarbonisation. In terms of hydrogen specifically, the policy on power is quite advanced—plus or minus, give or take—in comparison with the rest of Europe. That is something that we focus a lot of our analysis on, because a lot of the policy has been spoken about, defined, published and asked for.

On the specific targets, as Daniel mentioned, the ambition and the target are very much there, which is fantastic. What is still to be defined is the

policies that enable that target and unlock the flow of money. There is a lot of focus on that now, with the committee that we are having right now as well as the low-carbon hydrogen business model and, in terms of that long-duration storage, understanding that overall. I do not know whether Daniel has more to add.

Daniel Murrant: I agree. We have recently published some work on barriers to hydrogen deployment for flexibility, where we interviewed key stakeholders. I will not repeat myself, but the ambition and the policy in the UK are really good, which puts us in a good position to drive forward. As I have said, we are starting to fall behind on delivery. However, I am optimistic too. There is nothing here that we cannot correct, and we have the really good foundations to drive forward, but we absolutely need to drive forward, and that is where we are starting to fall behind a little.

Baroness Neuberger: Can you go into a bit more detail about the barriers in driving forward?

Daniel Murrant: One thing we find that I have talked about before is that planning is not co-ordinated, so there are long delays. Another big issue that we see is the chicken-and-egg situation where people do not want to invest in demand for hydrogen unless they can see that there is going to be production, but who wants to start a load of production if they do not know whether someone will be able to use it? So we need support to drive those two things forward.

Then there is the question of skills. I touched on this earlier, but 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. There were several others, but I have gone blank. I can certainly provide them in writing.

Another big one is the culture of risk aversity. I need to be really clear here: when we are investing in something like hydrogen, we absolutely want it to be safe and tested. There is no doubt about that. However, given what other European countries with very high safety standards are doing, there was a suggestion by some of the stakeholders we interviewed that we are perhaps too cautious, which again will slow down testing.

Caroline Still: To take the conversation to medium storage as well, the other barriers that we have heard mentioned by key stakeholders in the industry—if we are looking at the most advanced long-duration storage, which is of course pumped hydro—include the significant risk of capex overrun. The sort of drilling and infrastructure required for developing a pumped-hydro site can risk uncovering certain geological sites, and that can really risk capex overrun and add a significant cost on to those investments.

Additionally, to make the same point that Daniel just made about hydrogen, we are looking at significant construction requirements for pumped hydro storage and for carbon capture and storage, hydrogen, interconnector and grid buildouts. The risk is that these all compete for the same construction workforce across the UK.

On the medium-duration storage side, the grid connection delays are something that everyone is facing, so that is not particularly unique. There is the uncertainty around the changes to the TNUoS. Then there is the capacity market reform uncertainty, and the uncertainty of where that locational value of a specific asset is in fact quantified within the financials, and arguing that in a transaction.

Baroness Neuberger: We might be hampered, quite apart from everything else, by an absence of skills. Do those skills exist elsewhere in the world and not here, or do we need to build up skills from scratch?

Daniel Murrant: Skills are an issue that applies across the field of decarbonising. Particularly with regard to storage, a lot of these technologies are new, so I do not think the skills particularly exist elsewhere, but there are other countries that are driving it forward more quickly. One of the countries that were mentioned a lot as a good example when we did this study was the Netherlands. I do not think anyone has the pool of skills, but they have put actions in place to develop that skill set.

Baroness Neville-Jones: In the light of what you have been saying, something that I read—it might have been in the Royal Society report—talked about the need for demonstrators. Should we now be trying to do a demonstrator to work through some of these problems rather than endlessly talking, and are we in a position to do so?

Daniel Murrant: Absolutely. This applies to medium-duration and long-duration. When we talk to SMEs, they say they can do loads of testing of prototypes, but one of the barriers is getting that first large-scale plant up and running. That is where demonstrators and support for demonstrators can help. I am very conscious that there has been some support. There is the CRYOBattery storage facility, for example, which is the name for liquid air, which is part government-funded or has government support. So some has been done, but we definitely need more in future.

The Chair: Lord Holmes's question follows up on this.

Q8 **Lord Holmes of Richmond:** Thank you for taking the time to be with us today. What do you think the Government should do now to ensure that long-duration energy storage can be deployed at scale this decade?

Caroline Still: As we have spoken to, the key thing is the communication of any changes in policy as soon as possible, as soon as they are developed. At the moment, the uncertainty, from what we have seen in the work that we do at Aurora, is the key blocker to any flow of money and any meaningful deployment of medium and long-duration storage. Communication about locational premiums would help to alleviate this momentum-halter. Anything that can be done to mitigate that—this committee and the decision that will be made subsequently are part of it—will be key there. That is definitely my opinion.

Daniel Murrant: I have covered all this before. The definition of long-duration energy storage, some more detail, breaking that down, helps.

We need planning reform, so that it is easier to get through planning. We need co-ordinated strategic planning, so that we are looking across vectors and networks. For the very long stuff, we need strategic reserve support.

I want to park all that to one side for a moment. The other three are all trying to add certainty to make things a bit easier, which would allow new business models to be developed. Ultimately, that's the barriers – developing business models and being able to stack revenue, but if you add together some of the things that Caroline and I have mentioned, that will remove the barrier and help business models to develop.

The Chair: Thank you. That is the end of our first formal session. I thank our two witnesses, who have both been extremely informative. We have really appreciated your answers. I remind you that if there is anything you think would be useful to us that you would like to submit as evidence, we would be pleased to receive it. We are just at the beginning of this inquiry.