



Science and Technology Committee

Corrected oral evidence: Long-duration energy storage

Tuesday 19 September 2023

10.15 am

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

Evidence Session No. 3

Heard in Public

Questions 20 - 30

Witnesses

Timothy Armitage, Hydrogen Systems Consultant, Arup; Tom Lowe, Founder, Thermal Storage UK; Professor Pam Thomas, CEO, Faraday Institution.

USE OF THE TRANSCRIPT

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

Examination of witnesses

Timothy Armitage, Tom Lowe and Professor Pam Thomas.

Q20 The Chair: Welcome everybody. A particular welcome to our witnesses this morning. Thank you very much indeed for joining us. This is the third evidence session in our inquiry into long-duration energy storage. We are hearing from Timothy Armitage, who is a hydrogen systems consultant at Arup, from Tom Lowe, who is the founder of Thermal Storage UK, and remotely from Professor Pam Thomas, who is chief executive of the Faraday Institution. Welcome to all three of you.

We are being broadcast live on parliamentlive.tv, and a full transcript of the session will be made available after the meeting. You will have a chance to make any corrections that you wish to make. We will go round between us on various questions. I will start and we will take it from there. We have the bare hour, so we will have to be reasonably snappy.

You have each been invited to speak about different energy storage technologies: thermal, batteries and hydrogen. Could you comment on the role that each technology could play in providing energy storage for the grid?

Timothy Armitage: Hydrogen will play a central role as part of the future energy grid system. It is almost the Swiss army knife of that system, in that it is very good at quite a few different use cases. It is a very versatile energy carrier. It will decarbonise hard-to-abate sectors such as transportation, including aviation and shipping, industrial processing and potentially domestic heating.

Hydrogen is almost like an easy, low-risk option. We can repurpose much of the gas infrastructure. It is potentially the cheapest form of long-duration energy storage for terms of months, seasons and potentially even years. As an energy carrier, hydrogen is quite predictable and stable, in that the energy you put into a system in one year will be quite similar to the amount you take out in a year's time. It is very good at keeping energy safe for a very long period. For this reason, hydrogen is most suited for long-duration energy storage of seasons and years. It is likely to be used for system shocks such as one-in-30 weather events and potentially others like the recent war in Ukraine.

The Chair: Are there any downsides?

Timothy Armitage: Yes, of course. Any technology has its own niche advantages and disadvantages. I have stated the advantages.

One disadvantage is its round-trip efficiency. You lose energy during the production of hydrogen as well as during the end use of it. So it lends itself to a long use case rather than a short cyclic use case. It cannot compete on a daily or monthly use case with other technologies, perhaps, because you lose so much energy in the charge and the discharge of it, so it is more suited to long-term energy use over a seasonal period.

The Chair: Thank you. You know that we have heard from the Royal

Society and others. Can you say something about the maximum feasible scale of storage that could be provided?

Timothy Armitage: The amount of energy that could be stored with hydrogen is vast. We can repurpose much of the gas infrastructure and storage that we currently have for hydrogen. That includes salt caverns, which we have already, whether that is in Teesside or Cheshire. It also includes depleted gas fields in the North Sea and the east Irish Sea. Between them, those could have perhaps thousands of terawatt hours of capacity. A single gas field could have dozens of terawatt hours. In aggregate, the North Sea could have thousands of terawatt hours, which is far in excess of what we require as a country and potentially what Europe requires. Instead of overall capacity, the challenge for the technology is more in the deliverability.

Tom Lowe: I watched the evidence that was given last week. I would agree with the statements from those at the Energy Systems Catapult and Aurora Energy Research about trying to distinguish between medium-duration storage and longer-term inter-seasonal storage. As Tim has rightly pointed out, with hydrogen there is a use case for inter-seasonal storage, measured in weeks, months or potentially years.

Thermal storage has more of a role in the 24-hour use case, at the opposite end of the spectrum. We are looking at days rather than months or even years. By "thermal storage" I specifically mean products that work for electric heating and industrial heat processes.

One of the main advantages of thermal storage is that you reduce your peak demand. If we electrify significant portions of the heating systems in the UK for both domestic and business, and we electrify industrial processes, we will see a significant increase in the amount of electricity used. There will potentially be a doubling by 2050. At peak times, that could be up to four times current peak demand. There are ways to reduce that peak demand. There are multiple technologies that can help with that, and thermal storage is one of those.

In the 1980s, the energy system had the Rough gas storage facility, which was very big, and things like Dinorwig, which it still has, for pumped hydro. We also had storage heaters in domestic homes. The future energy system may look quite similar to that, with some role for hydrogen, electrochemical batteries and thermal stores.

I have a couple of other thoughts on thermal storage, which maybe differentiate it slightly from hydrogen and electrochemical batteries. First, we are not looking at round-trip efficiency in the same way. We are not looking at converting this to another medium and then converting it back into electricity, which is what Tim just described for hydrogen, for instance. There is definitely a role and a need for that. This is about turning electricity into heat and then storing that heat for later use.

With thermal storage, we are also talking about kilowatts and megawatts. We are not talking about gigawatts or terawatts. Once you sum up each of those individual products, though, there could be quite a lot of thermal storage on the grid by 2030 or 2050.

Professor Pam Thomas: Battery technology and energy storage systems have already been deployed extensively both in the UK and worldwide. Of course, battery technology is most widely known for its use in battery electric vehicles. However, it is not and should not be considered as being confined only to the automotive sector.

The principal job of the Faraday Institution, which is the UK's premier research organisation for electrochemical storage, should be to set out where and how battery technologies can be deployed more widely for the benefit of the UK—hence, we are particularly pleased to be invited here to discuss the question of batteries for long-duration energy storage. This coincides rather nicely with the launch today of a report commissioned by the Faraday Institution, which is a market and technology assessment of grid-scale energy storage and the role of batteries. We would be very happy to submit that, if it would be useful.

The Chair: We would be delighted. Thank you.

Professor Pam Thomas: In terms of overall suitability, lithium and sodium-ion batteries are highly adaptable for grid storage, serving a broad range of grid flexibility applications due to their high energy and power capability and quick response times.

Lithium-ion batteries in particular have exceptional performance in response time, discharge duration and round-trip efficiency, making them a versatile choice for multiple grid flexibility applications.

Sodium-ion batteries are somewhat behind in their development, but, as I will come to later in our discussion, they are very important for the UK to consider as a technology for the future. They display similar properties to lithium-ion batteries with regard to response time, discharge duration and round-trip efficiency.

I should emphasise what one of my colleagues on the panel has just said. We need to consider the duration time. Lithium and sodium-ion batteries are exceptionally useful for storage times that are typically in the range of two to four hours. With later installations, that may be up to 10 hours. We note that there is a lithium battery installation going on to the California grid with a 10-hour duration time. That is their range of applicability.

I hope we will talk later about redox flow batteries, which go into the days to weeks element of storage. We can then look at lithium-air batteries, which are still being researched. Those would be up to hundreds of hours of storage.

You can see that battery technology across the piece has various roles to play, alongside the other technologies we are discussing, to fill in particular parts of storage, grid stability and so on. That is what I would like to say in opening.

The Chair: Thank you. We will probably come back to the matter of how long things can be stored for.

Q21 **Viscount Stansgate:** Having made your opening remarks, my question

to you is about the advantages and disadvantages of each. The Chair, in fact, already asked Mr Armitage this. I am almost tempted to ask whether each of you agrees with the advantages and disadvantages, and what you have to say about the technologies you are talking about.

Genuinely, it is important to know what you think are the disadvantages. In a way, it is also important for you to predict what niche in the energy storage business your technology best fits. I will ask you to take it in turns. You might want to restate it in a nutshell, Mr Armitage, as you have already answered the question, but by all means go ahead first and mention it.

Timothy Armitage: I will just reiterate some of the advantages and use cases for hydrogen. This is a technology that is very similar to our current gas grid, in that we can repurpose much of the gas infrastructure that we currently have, including some of the natural gas storage that we currently have in salt caverns and depleted gas fields.

You may view it as a low-risk option, in that we already know much of the technology around it, albeit at a very small scale compared to where we need to get to. However, much of the technology and the capability required for this is already present in the UK.

Another advantage is that it offers very long-duration energy storage—over a period of months, seasons or years. The energy you put into the system will be similar to the energy you take out at the very end.

The disadvantage is the round-trip efficiency. You cannot get away from that. The Royal Society report puts the energy you lose in the production and end use of hydrogen at around 40%. That is about accurate.

What does this make hydrogen useful for? It is not for that short use case scenario; it is that very long-term view. That is how we use hydrogen.

Tom Lowe: I would agree with what Tim said about the advantages and disadvantages of hydrogen.

On thermal storage, one of the main advantages is the product itself. There are different types of thermal storage. Sunamp, for example, is using phase-change materials based on sodium acetate. That is a fairly common material that is fairly easy to get hold of and transform into the phase-change material used by Sunamp. Other Thermal Storage UK members such as Caldera use products such as recycled aluminium and volcanic rock in their product. Again, those are reasonably straightforward to obtain.

I mention the ease of accessing those materials and metals, because if I make a comparison with lithium-ion, for example, it is well-known that there are supply constraints and geopolitical issues with lithium. That does not affect the performance of lithium, which, as Professor Thomas has said, is very good for a two, four or six-hour period, but it makes it harder to obtain. Thermal storage has the advantage that we use readily available metals and materials.

Another advantage to thermal storage is that we are manufacturing it in the UK. We already have a supply base. Sunamp, the largest member of the trade association that I run, has already produced 20,000 units. That is small in the grand scheme of what we have to do to electrify heating in the future, where we have 25 million homes that we need to transition over from current heating systems to something else, such as electric heating heat pumps or thermal stores. We are building up a manufacturing base and we have companies here with patents, and patents pending, for technologies that are world leading.

There are some disadvantages; the question was to look at disadvantages as well. I have already mentioned that with thermal storage you are really converting one way: you are converting from electricity to heat. That is the primary use case for that electricity. You are not going to be converting it back into electricity. If you want something on the grid that does that at scale, you have to look for other technologies.

We have a lot of space heating needs in the UK. At the minute, the gas system alone is delivering about 300 gigawatts of heat at peak times during winter. We will not be able to use natural gas certainly by 2050, so we will need to find some other way of getting that 300 gigawatts into people's homes. Heat pumps will be one way of doing that; thermal stores will be another. So there is a disadvantage, which is that you can convert it only one way, but there are advantages there as well.

My final thought on thermal storage's advantages and disadvantages is that the benefits of thermal storage to the electricity system depend on how much we electrify heating. 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 and try to get as much long-duration storage out of them as possible.

People from the Climate Change Committee and the UK Government think that 50% to 80% of homes will have heat pumps, which means that 50% to 80% of homes will have some form of thermal store. You may as well try to use that as much as possible. If we decided to do something other than electrify heating, for instance, you might not get the benefit because the thermal stores might not be there. So it is an advantage and a potential disadvantage.

Professor Pam Thomas: As a preface to my advantage and disadvantage remarks, having listened to my colleagues' comments, this will be a mixed economy in the end, using various types of technologies for different aspects of it. That is coming out from what colleagues are already saying.

On the advantages of deploying lithium-ion batteries into the grid, it is a mature technology. It is already in use. The first deployment that I could find of a lithium-ion battery into the UK grid was back in the 2010s. The cost of the batteries is coming down as they are being produced at scale. In a sense, they have been pretty well characterised because of the need to drive around safely in cars. I will come back to safety in a minute. In some sense, they can be seen as reliable. One knows what the

technology can do and what it cannot do; it is already working in a wide range of grid services in that short-term, fast-delivery, agile and responsive mode. Those are the particular advantages.

One disadvantage might be perceived as issues with safety. That is where continued research is really important. In particular, going to the next generation of sodium-ion batteries, which offer many of the same usage advantages but are inherently safer, would be a solution to that. That would also bring down costs. Going over to other chemistries such as sodium-ion would produce a cost saving over time, because sodium is naturally more earth abundant and we can access it here in the UK.

Another possible disadvantage at the moment is that we are not producing lithium-ion batteries in the UK, although that is about to change over the next couple of years due to the gigafactories, with the most recent gigafactory being placed in Bridgwater under Agratas. There is something about having our own sovereign capability to produce these batteries for the grid, and we might want to keep that in mind. At the moment, we do not have a stationary storage battery industry of our own in manufacturing and production terms. We have a lot of the ancillary things around it for managing batteries—battery management systems and so on—but perhaps not our own manufacturing capability, which is something we might think about.

Going from that short-term highly flexible contribution to the grid to redox flow batteries, which are the longer-term storage solution, we have very good research on those. We have some production and some deployment. A company called Invinity has recently received an £11 million grant to look at deploying a redox flow battery solution for the grid. Scale-up is what I would look at there. If we really want to deploy this technology across the UK's grid solution, what plans do we have for scaling up? That would be another disadvantage.

Other solutions, such as metal-air batteries, are still something for the future. We need to do long-term research on those to work out exactly where they fit into our grid picture.

Q22 Viscount Stansgate: Could you briefly outline the long-term cost projections for the storage provided by the technologies that you have each been talking about?

Timothy Armitage: To give you a very quick answer, hydrogen storage lends itself to an economy of scale. You can store terawatt hours of energy with hydrogen. You can scale that up very easily through depleted gas fields or lots of salt caverns being deployed at the same time. However, it is a very capital-intensive operation. The capex for this is up front and very expensive. However, the operational expenditure is relatively very low compared to the total amount of energy you can store.

Tom Lowe: I will keep this brief, but it depends on the product. It depends on whether you are looking at using it for heat, space heating, hot water heating or for industrial processes. For domestic properties, the current thermal stores in the market are retailing for between £1,000 and £8,000. That is before you apply any grants, such as the boiler upgrade

scheme, where they are available for thermal store, or the 0% loans that are currently available from the Scottish Government. The capital cost is £1,000 to £8,000.

For industrial processes, one of the Thermal Storage UK members, Caldera, is currently building a demonstrator project. It projects that the industrial thermal store will be approximately a third cheaper than the equivalent electrochemical battery of that size. That is a demonstrator project. It hopes that the cost will come down, but it has to demonstrate it. That is the point of the demonstrator.

We would expect the capital cost to fall, in the same way as it has for electrochemical batteries as manufacturing has scaled up and take-up has increased. At the minute, in the smart thermal storage market, you are looking at 30,000 to 40,000 units a year globally, which is quite small. The potential is millions of units a year. You would expect to see improvements in the capital cost as you scale up manufacturing.

Professor Pam Thomas: In terms of storage costs, the price point we are always aiming for with lithium-ion and sodium-ion batteries is less than \$100 per kilowatt hour.

Respecting that there can be volatility in the market for these minerals, including a huge spike in the price of lithium carbonate earlier this year, the fact that these technologies, particularly lithium technologies, have gone through that scale-up procedure means that the costs have been pared down to that kind of scale.

There is one other point that I forgot to make. This is geographically agnostic: you can put a lithium-ion battery anywhere, you can move it, as opposed to it being connected to some kind of geographic feature. That is another advantage that I forgot to mention.

The cost at scale is coming down all the time. On a low-cost scenario for sodium-ion, we are looking at a price point of US\$83 per kilowatt hour in 2030, which is certainly extremely competitive with any other technology.

Q23 Lord Borwick: I have a quick question for Mr Armitage. When you look at efficiency, you are talking about the electricity in and the electricity out. But the type of electricity that is produced by wind turbines could be surplus electricity; a storm at 2 am will produce far more electricity than we can use in the UK. If we were to use that electricity for making the hydrogen, would we be right to look at it on the same basis of efficiency? Should we use some other way of judging it?

Timothy Armitage: You make a very good point here. We can get perhaps too hung up on the efficiencies of storage technologies. In the UK, we have vast renewable energy potential. If we have surplus renewable electricity compared to the demand, we are not really worrying about efficiency but worrying about capturing as much energy as possible overall, potentially with a very large deployment of renewable energy, such as lots of wind energy.

We can get too hung up on efficiency. Instead, we should be trying to incentivise as much deployment of renewable resources as possible and

then being able to capture that in total rather than the overall efficiency of the product.

- Q24 **Lord Sharkey:** How effective is current government policy at supporting the development of your particular technology for grid applications? In particular, do the current electricity arrangements or other subsidy regimes support the development of your technology?

Timothy Armitage: The 2021 hydrogen strategy outlined the case for the hydrogen production business model. As part of this, it is recognised by government that hydrogen storage and hydrogen production go hand in hand and one is a prerequisite for the other. As part of this, there is some government support to help for storage. This is mostly via surface tanks above ground at a very small scale. By no means is this adequate for grid-scale utility and underground hydrogen storage.

This has been recognised by DESNZ, which is looking to produce the hydrogen storage business model by 2025. This business model was recently set out with a minded-to position by the Government. As part of this, they are looking at a cap and floor mechanism. They want to focus on deliverability, the scale of the issue, delivering on time and delivering projects that are low-risk.

Arup and I are working to help to deliver this storage business model, but it has to be correct. It has to have the right application in order to unlock private sector investment and to make sure that we reach the adequate scales of storage required by 2035, when we decarbonise our electricity grid, and by 2050.

Tom Lowe: Thermal storage is now typically connected behind the meter, which means that it is in somebody's building rather than necessarily being connected at grid level. So it is slightly different from the answers Professor Thomas will give and the one Dr Armitage just gave.

The good news is that UK Government policy is increasingly recognising the role of thermal storage and heat flexibility. The Government are currently working on technical standards for Energy Smart Appliances and smart heat mandates, which we are expecting to be introduced through secondary installation in 2025-26, once the Energy Security Bill has finally passed through Parliament.

The Government are looking to support domestic installs of electrified heat. As I have already emphasised, things like the Boiler Upgrade Scheme are important to make sure that we get enough heat pumps with thermal stores installed. They are also working on the decarbonisation of industrial processes. There is currently a fuel-switching competition which the Government are running, and there is also a currently open consultation and call for evidence on the electrification of industrial processes.

The Government are looking at the issues. There are some areas where we could see more from government. I would split those into three areas. One is lowering the operating costs of flexible products. The second is

lowering the capital cost of those products. The third is recognising that flexibility across the system, including in energy performance certificates.

I will briefly outline what I mean by those three things. At the moment, there is perhaps a lack of recognition of the benefits of flexibility within the pricing of the energy system. You asked about the review of electricity market arrangements. Today, we have a system that is still essentially trying to flex power generation to the demand that is on the system rather than what we will increasingly do, which is to flex demand where we have high levels of renewables on the system.

To have the smart time-of-use tariffs that we want to have in order to incentivise flexibility, we need to complete the smart meter rollout. I will not be the first person to have suggested that to this committee. We also need to move to market-wide half-hourly settlement, which we are expecting in 2026. That has already been delayed by one year. We also need to encourage or, if needs be, to mandate energy retailers to offer time-of-use tariffs.

On the capital side, there are some differences in treatment between thermal stores and other electric heating products at the moment, which we think the Government should look to address. One is the VAT treatment of energy-saving materials. Today, if you were to get a heat pump with a thermal store, the whole product would be VAT rated at 0% as an energy-saving material.

If you later on added a thermal store to your heat pump, it would be charged at 20%. If you had a thermal store installed on its own—there are products out there, like those made by tepeo, that can work like that—you would be charged 20%. That is also true for electrochemical batteries installed in homes, unless they are installed alongside something like solar at the same time. We have asked Treasury to look at extending the VAT rate reduction from 20% to 0% for thermal stores. We may see that in the Autumn Statement.

We also think that the boiler upgrade scheme is too narrowly defined at the moment. It is a boiler upgrade scheme; it should cover a range of technology types. It covers heat pumps and biomass, but it does not cover thermal stores. We think that is a missed opportunity.

Finally, I mentioned energy performance certificates as an example, but there are other parts of the regulatory framework, like the energy-related products policy framework, where flexibility is not considered. You could have a home where you have insulated or changed your heating system—you might have installed solar—but if you have installed a battery, a thermal store or an EV charger, the current energy performance certificate would ignore that completely at the end of the day. We think that EPCs, the energy-related products policy framework and other parts of the framework should consider and recognise flexibility, which is currently missing.

Professor Pam Thomas: I will answer this, if I may, from the point of view of leading a research organisation. It will be a little different from what you have heard from my colleagues on the panel.

From our point of view, looking out at the research landscape of the UK, it seems that there is no concerted programme on battery storage for the grid. We are in that space because it is part of our remit to look at that, although we do not have hypothecated funding for it. Most of our funding so far has been from the automotive sector.

It probably will not surprise you if I say that I think there ought to be a programme to look at how we deploy battery technology properly for the grid, not just the current technologies that one can purchase and site, but future technologies that might provide significant advantages in the parts of the spectrum in which batteries play a role.

In particular, there does not seem to have been a concerted research programme as there has for automotive batteries and for redox flow batteries. Looking around the landscape, there are several projects going on, which are of high quality. I particularly noted a research project that is being funded through European money on Germany's large-scale research effort into long-duration storage. It is called SPRIND. That is giving big funding to redox flow battery research in Manchester. There is a gap in what the UK is doing to muster its forces around future possibilities for home-based, UK-based, battery storage for the grid.

Q25 Lord Sharkey: Following on from those remarks, can I ask each of you very briefly to say whether there are any ongoing projects that are particularly notable and that we should look into? One example perhaps is the area of depleted gas field storage, which I know Arup went into in some detail in its written submissions. Are there any particular ongoing projects that you would like to draw our attention to?

Timothy Armitage: There are numerous projects within the hydrogen space that are notable. Although they are small steps on our road to the required amount of long-duration energy storage, they are still significant and certainly should be noted.

The first one I would like to mention is the HyKeuper project in Cheshire. This is part of the Cheshire salt and is a collaboration between INOVYN and the HyNet industrial cluster. As part of this, 19 salt caverns are being developed here, ready for hydrogen storage. They are due to come online later this decade and early next decade. In total, they have a storage capacity of about 1.2 terawatt hours, so perhaps a percentage point of the overall storage capacity that we need. However, this is still a significant step considering that we do not have a hydrogen storage business model already in operation.

The next one is the Aldbrough salt cavern that is being constructed on Humberside. That is similar. It is due to come online either later this decade or in early 2030 with a similar scale.

In terms of the depleted gas field, anecdotally we have been speaking with Centrica and the Rough gas field storage facility. As part of their hydrogen business model, they are looking to, and they want to, convert it, ready to be used for hydrogen storage. It could have a capacity up to 10 terawatt hours of energy. It is important to note that this is less than the amount of energy that is currently stored in natural gas there.

However, it is still perhaps a strong step on the road to the overall storage capacity that we will need.

These show that there are commercial operations. Business does want to convert towards long-duration hydrogen storage. It is just trying to unlock that, incentivise that and unlock private sector investment in this sector.

Tom Lowe: I will draw the committee's attention to three projects. One I will mention in passing and two I will go into a little bit of detail on. I have provided some of this in written evidence as well.

I mentioned the company tepeo in passing. It has a thermal store that operates instead of heat pumps. It is working with the energy supplier OVO and the energy network UK Power Networks on a project called NeatHeat. That is looking at trying to balance the distribution grid, which we have not really talked about yet but we may come back to. That is an important part of the infrastructure upgrades that we need in order to meet net zero by 2035 or 2030.

Looking at more long-duration storage, I would point the committee's attention towards Sunamp's project EXTEND, which received funding from the longer-duration energy storage competition. I know you have people giving evidence on that after this session. That is looking at extending the life and the capacity of their thermal stores. Rather than it being directed more towards limited space heating or hot water, it would look instead at capacities from 50 kilowatt hours to 300 kilowatt hours. These products are the same size as a large fridge or an American-style fridge freezer, so they are much bigger than the normal thermal store we would be talking about with Sunamp and its phase-change technology. They are also working on that project with companies like myenergi.

The other project I would look towards is the Caldera project on industrial heat processes. That is the demonstrator I have already mentioned. That is funded partly through the UK Government's £55 million industrial fuel-switching competition, which is part of their £1 billion net-zero innovation portfolio. That product could provide up to 2 megawatt hours of storage per modular unit. Caldera is also working with an NHS trust to evaluate a district heating solution for its hospital campus.

The fact I have mentioned a couple of government competitions there also demonstrates, going back to the previous question, that there is policy support and funding support that is not insubstantial; we are talking about tens of millions of pounds going towards exploring these technologies.

Professor Pam Thomas: I have already mentioned the redox flow project in SPRIND. I would also draw the committee's attention to the outturn of the Energy Superhub Oxford project, which has been deploying batteries and solar together in the electrification of the city of Oxford. This project has now officially concluded after four years. The final report is available. It is a very interesting and useful read concerning how these technologies can be put together to achieve the aim of a net-zero city.

I would also draw your attention to one of the Faraday Institution's research projects on sodium-ion technology, which we hope to take from research to a demonstrator. We are trying to put that in place to have a sodium-ion battery as a demonstrator for the grid. That project is called NEXGENNA, and it is led out of St Andrews. It has also had significant investment for a prototyping facility up in St Andrews to take the research findings and translate them into the start of industrialisation. I would recommend that the committee keep an eye on that one.

Q26 **Baroness Northover:** I need to start by declaring an interest as a member of the board of Pensana, which sources critical minerals in Angola to process in the UK for magnets to use in batteries for EVs and wind turbines.

Is the relevant education and skills strategy in place to deliver what we are talking about?

Professor Pam Thomas: The electrification of the passenger automotive sector gives a relevant comparison for the need for skilled workforce for grid infrastructure. A notable initiative in this regard has been the collaborative effort between the Faraday Institution, WMG and the High Value Manufacturing Catapult to create a blueprint for the National Electrification Skills Framework and Forum (NESFF), which it has now been announced will be led out of Coventry University. That is about providing 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. There has been work to put that framework in place for how the UK should be looking to produce that upskilling right across a range of skills required from level 3 to level 8. That is the NESFF, which again we could submit to you if you do not have access to it already.

At the heart of that framework lies the concept of foresighting, which involves the co-operation of industrial stakeholders, accrediting bodies and training providers to identify the existing training provision along with the critical gaps. There is a procedure there to make sure that the UK will be properly tooled up, as it were, to provide this skills training.

I do not want to dominate this any more, because we can let you have the report, if that is helpful.

Baroness Northover: That would be very helpful.

Timothy Armitage: Our existing gas infrastructure lends itself very well to being repurposed for hydrogen. However, we have a severe bottleneck in the production of new infrastructure. We need to upgrade the number of engineers and geoscientists in this space significantly. There are only a couple of companies in the UK that can construct and deliver salt caverns. If we are talking about delivering hundreds of salt caverns, we will have significant supply chain constraints, including the topside requirements, the wellheads involved and the gas network infrastructure, which will need to be repurposed to be hydrogen ready. There are

significant challenges in the deliverability of this. Those are mainly to do with the supply chain constraints.

Tom Lowe: I agree with the underlying points in what Dr Armitage just said. We have great engineers in the UK. We just do not have enough of them. That applies to manufacturing, installations and grid infrastructure upgrades.

In the domestic heating transition, we have worked out that we will need to operate 350 homes every working day for 27 years. We are currently grading that as a weekly or monthly figure, rather than an hourly figure. That is just on the heat side, not thinking about the manufacturing angle at all.

One thing we have not talked about much is that this is a global challenge. There will be other companies in other countries doing some of the innovation and manufacturing work for us, but UK manufacturers have a big role to play. We need ten or a hundred times more engineers than we currently have.

Q27 **Lord Rees of Ludlow:** Again, this is a question for Dr Armitage about hydrogen in connection with the scalability of this project. The Royal Society report, which you have heard about, focuses on caverns in Yorkshire, et cetera. You mentioned other possibilities, including undersea.

More generally, I would like to ask two questions, first on the capital cost and the scalability of getting up to 100 terawatt hours of storage. The second is about the public reaction. Is it rather scary to the public to have these enormous storages below the land? How feasible is it to get this enormous scale of storage by 2050?

Timothy Armitage: The scale of this task is significant. Especially considering where we are currently, 100 terawatt hours is vast. We also should recognise the timescale required to get there. This is not a light undertaking at all.

My own research and the University of Edinburgh has shown that single gas fields, such as the Leman gas field, could perhaps hold c. 800 terawatt hours, which is enough to fulfil the UK's capacity alone. In aggregate, the North Sea has somewhere around 6,000 terawatt hours in total. That is a significant number. It is far in excess of what we need and far in excess of what Europe needs. There is a potential for the UK to export energy storage capacity abroad with this.

The British Geological Survey and my colleagues at the University of Edinburgh have done similar reports on salt caverns in Cheshire, East Yorkshire and the Wessex Basin. They are finding similar very large numbers: thousands of terawatt hours of potential hydrogen storage.

The technical capacity is here in the UK. We have the correct geology. Instead, it comes back to this idea of deliverability and how easily we can deliver this on time and at cost. We are looking at the regulation behind this: the competition for land use, the supply chain, the government

support for this and the hydrogen storage business model. These are key components of the overall picture that we need to get right to deliver the scale on time.

You raise a very good point about the considerations and the safety case. Hydrogen is not the be-all and end-all; it is not necessarily agreed that hydrogen will be answer. The Hydrogen Village trial has shown that the public need to be brought on board and we need to sell this technology to the wider community. That involves very clear stakeholder engagement and requires us to show unequivocally that this technology is safe for large-scale use. I believe we have the capability to make it safe. We have that capacity, and we have that technology. However, it is about demonstrating this unequivocally for the perceived safety case. The perceived safety case needs to be correct, and it needs to be safe. We cannot just say to people, "We're going to build all of these hundreds of salt caverns under Chester". That is not going to happen. Instead, we need to bring them on board and we need clear stakeholder engagement as part of that.

Lord Rees of Ludlow: We must think of the Hindenburg disaster, perhaps.

Timothy Armitage: That is a banned word in my work.

The Chair: Thank you, Lord Rees. That has really cheered us up.

Q28 **Lord Borwick:** Particularly for Professor Thomas, I have three questions. What is your view on the challenges to the commercialisation of redox flow batteries?

Professor Pam Thomas: There is a challenge of bringing the cost down. There is a challenge of perceived reliability. In the UK, we have not had a big programme to look at what they can really do for us.

There are redox flow projects across the UK. I particularly noted the Manchester project, which is about looking at membrane-less technology. That would certainly bring the cost down radically, because the membrane is a very expensive component.

There are also questions about the toxicity of the chemicals and the accessibility of vanadium. Many of those in commercial production now are vanadium redox flow batteries. I believe 80% of the vanadium pentoxide resides in China. There are questions about looking for other chemistries that would be more geopolitically available in any given circumstance.

There is a lot of potential there. The UK should be upping its game in looking at how to deploy those at scale within the energy storage solutions we have to hand. There is more work to be done to get it to the right level of technological readiness to prove its reliability and lower the cost.

Lord Borwick: What about other novel or next-generation battery technologies? What is on the horizon that has not been looked at yet?

Professor Pam Thomas: Sodium-ion has been looked at but not yet been deployed widely. I have already referenced that a couple of times in my answers. At the Faraday Institution, we believe there is an opportunity there for the UK. Although we are a little bit behind what is developing in China, we have a lot of experience and, indeed, we owned the IP in that space with the company Faradion. We have a real knowledge base there, so we can say we have a leadership position.

That is coming along the line. It is predicted to be about 7% of the battery energy storage market by 2025, according to the report I mentioned at the beginning of this session.

We also have metal-air. That is further off. We have more problems to solve.

Lord Borwick: I am sorry. What is metal-air?

Professor Pam Thomas: The anode is just a metal. There is less component material to begin with. It is less expensive. You do not have the same critical minerals conditions that we have when we consider today's batteries.

Lord Borwick: Everybody has said that second-hand lithium car batteries will be used as long-term storage. Is that your view? Will car batteries below 80% capacity get a second use as long-term storage?

Professor Pam Thomas: It is a possibility. We will have to think very carefully about whether we would prefer to have a proper recycling industry and get the minerals back instead. That is an open question and one for the future. It will be about the economics of redeployment versus recycling.

I would have a question about safety. We would need to know the history of a battery, whether it had been in an accident, abused by a careless user or charged in the wrong way over its life, before we would want to put it in somebody's backyard. One would need to put in a lot of regulation around battery history or a battery passport with everything that had happened to it. Is it a safe thing to put on to a microgrid or even the main grid? That needs to be looked at in the round with proper policy and regulation.

Lord Borwick: I thought most lithium battery explosions came from bad manufacture of the battery rather than misuse of the battery in use. If a battery has been used in an electric car for three or four years, has it not proved its safety?

Professor Pam Thomas: I do not want to be drawn on whose fault battery fires are. I apologise for that, but I understand what you are saying. That may well be the case, but we have to consider and regulate how we would do that. I would presume that we would not want any old Tom, Dick or Harry deciding to take out their car battery and connect it to the grid. You would have to look at how that was to be done, what the conditions were, and the level of safety and good husbandry of that asset over its life.

Q29 **Baroness Northover:** This is particularly to Tom. Hello. In some ways you have answered some of these points. Are there any companies in the thermal storage space that are looking to develop large-scale projects for either grid storage or district heating storage applications? Do you have a view on whether thermal storage can reduce the need for electricity storage on the grid? You have addressed that. Could you cite any research that has been undertaken into this?

Tom Lowe: I have answered the first two parts of that question by referencing those projects from Sunamp and Caldera, so I will not repeat that now.

On the studies, we did a piece of work with a company called LCP Delta, which is a consultancy, looking at the future capacity—it went out to 2030, so not that long into the future—for thermal storage to provide the grid flexibility we have been talking about. Even with some pretty conservative assumptions, we were looking at 4.1 gigawatts of peak demand reduction.

There are other studies out there, which I am happy to share afterwards with the committee. We have one report coming out today, which I will share, looking at the network modelling aspects of all the questions we are talking about today and trying to work out how you look at the flexible energy system that we need by 2035, 2040 and 2045.

Decarbonising power is not a question of hitting the target in 2030 or 2035. It is something you have to keep doing every day once you have got to that point. As you electrify heat demand and transport demand, how do you keep the power system at zero carbon? I will share that report with the committee afterwards as it is fresh off the press.

Q30 **Lord Wei:** Our report will make recommendations to the Government to help shape their policy towards long-duration energy storage. What key recommendations would you have for government policy, if they wanted to support the growth of your technology and deploy long-duration energy storage at scale? We will start with whoever thinks they should answer first. We do not have to have everybody answer.

Timothy Armitage: I would just like to reiterate the scale of the challenge, the timescale for delivering this and the supply chain constraints. They are very tight, and we have a very short window of opportunity to act now before it is too late, to go hand in hand with decarbonising the grid by 2050.

There are a couple of recommendations that I would make. No one technology presented here will be the answer. We need a diversity of technologies, whether that is batteries, thermal energy storage, compressed air energy storage, pumped hydro or hydrogen. All of these have a niche and a role to play in a decarbonised grid.

Specifically for hydrogen, we need to effectively unlock private sector investment and the supply chain constraints with the hydrogen storage business model. This needs to be delivered on time, at pace and at scale. There is a role for you to hold that accountable and to make sure this is done correctly.

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. We also need a holistic systems-led approach to this. We need to co-locate our storage effectively with hydrogen production and hydrogen demand. We are talking about an integrated system with overall master planning and a direction of travel that everybody can buy into.

We have the potential to support massive growth. We have the opportunity here in the UK, both geological and economic. We just need to make this a reality by unlocking that private sector investment and by getting the hydrogen storage business model delivered on time.

Tom Lowe: I have already mentioned extending the VAT relief for energy-saving materials to get the capital cost down; looking at the potential to expand the boiler upgrade scheme, which again would get the capital cost down; ensuring that the operating costs reflect the fact that the system should be more flexible and valuing the flexibility of utilising renewables wherever they are plentiful, so we avoid having to turn on gas back-up power plants, for instance; and making sure that the energy performance certificates and the energy-related products policy framework reflect the flexibility of the system. There will be other things on industrial processes, but I will save those for another time.

The Chair: You could even give us some of that in writing.

Professor Pam Thomas: I would add long-term support, a clear direction of travel and an understanding that it is a holistic horses for courses approach that will need a combination of technologies to achieve.

Lord Wei: Given that we have run out of time, I would value some written answers, particularly on this question of why there is not enough political support for this and what could be done about that, given that the costs will be quite major. I would love to read your answers to that question.

The Chair: We would really love you to submit some written material on that. Can I say a big thank you to all three of our witnesses?