



Science and Technology Committee

Corrected oral evidence: Long-duration energy storage

Tuesday 12 September 2023

11.15 am

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Members present: Baroness Brown of Cambridge (The Chair); Lord Borwick; Viscount Hanworth; 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. 2

Heard in Public

Questions 9 – 19

Witnesses

Professor Sir Peter Bruce, Physical Secretary and Vice-President, The Royal Society.

USE OF THE TRANSCRIPT

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

Examination of witnesses

Professor Sir Peter Bruce.

Q9 The Chair: Welcome to the second session of our new inquiry into the role of long-duration energy storage in the UK's future electricity system. We are delighted to have Professor Sir Peter Bruce, physical secretary and vice-president of the Royal Society, as our witness. The Royal Society has, I believe, just published an important report on long-duration energy storage, so we are looking forward to hearing from you about that.

The session is being broadcast on parliamentlive.tv, and a full transcript will be taken. We will send that to you shortly after the session and welcome any minor corrections that you may need to make. If, in addition to the Royal Society report, there is any further information that you think would be useful to us after this session, we would be delighted to receive it as formal evidence for our inquiry.

I will ask the first question. Could you outline for us the major conclusions of the Royal Society report, how it perhaps differs from earlier work, and how it compares with other work that is out there in the literature, such as some of the Climate Change Committee scenarios, if you are aware of those?

Professor Sir Peter Bruce: Thank you very much. It is a pleasure to be here and to see you all again.

The report's main conclusion is that, in almost any realistic decarbonisation scenario for the UK, we will need large amounts of storage. By that, I mean anything from perhaps 40 terawatt hours to 100 terawatt hours of storage. We looked at the most cost-effective scenarios, and the most cost-effective way of delivering a decarbonised GB grid would be to base it on wind and solar, with storage by hydrogen. That, in our analysis, delivers the lowest-cost option.

We also considered two other factors in coming to those conclusions. One was the technology readiness level of various alternative ways of decarbonising the grid. The other was the energy security aspects—if you like, the sovereign nature of that electricity grid. Those were the more subordinate considerations in coming to our conclusion.

The amount of storage is certainly reduced by having a mix of generating technologies, including nuclear, for example, some methane, some gas, plus CCS. We think that is the right direction of travel, but even in that scenario, even with significant amounts of nuclear or even methane plus CCS, one still requires 30, 40 terawatt hours of storage. To give a sense of the scale, 30 terawatt hours of storage is about 1,500 pumped hydroelectric power stations. Denorwig in Wales was the last one that we built in the UK, so you would need 1,500 of those to deliver the storage. We are not advocating that as the solution; it is not practical, for all sorts of reasons. It just gives a sense of the scale.

To the point about how our conclusions might differ from some others out there, the real thing that is driving that large amount of storage is the weather patterns over 37 years. We analysed the Met Office's historical data for that period, looking at the supply and the demand and matching hour by hour. It is only when you look over decades that you realise that there are periods when, to keep the lights on, you need that level of storage. In one decade alone, there were three consecutive years when the demand would significantly outstrip the average supply. So even building extra supply and curtailing would not solve the problem, certainly not economically.

That, perhaps, is the main difference from some of the other reports that have looked at one year; they tend to underrepresent the amount of storage needed and overrepresent the amount of gas plus CCS.

Q10 Lord Krebs: I declare an interest as an adviser to Drax, the energy company that operates Selby power station, among others.

On the last point, when you looked at 37 years of data, the old mantra that the past is no guide to the future is particularly appropriate for looking at weather patterns that are influenced by future climate change. Could you comment on that?

Professor Sir Peter Bruce: Yes, you are absolutely right. The benefit of historical data is that it is accurate. The downside is that it does not help in predicting the future.

We talked to the Met Office about the impact particularly of climate change on our weather patterns. Its conclusion was that the main effect on generation would be greater variability in wind. There would be more extreme wind patterns, where we have periods with virtually no wind and periods with very high levels of wind. The discussions with it concluded that we should build in a 10% contingency into our analysis. We made it 20% to be really sure that we had addressed the question of changes in the climate, as well as one can ever predict the future, and its influence on the generating capacity hour by hour.

We also considered the fact that, if the UK becomes significantly warmer, in summer there may be a greater use of air conditioning, which to some extent helps load balancing if you are using the same heat pumps in the winter to heat and in the summer to cool. That was built into our analysis, too. It has a relatively small effect.

The Chair: Did you consider that, as we gradually move to being able to do floating wind off the west coast of the UK, we will not be reliant only on the northern European wind systems? We will also have the Atlantic weather systems contributing to generation, which could give us at least different weather patterns rather than all our generation coming predominantly from one weather pattern.

Professor Sir Peter Bruce: Absolutely. That was really the main outcome of the analysis of how climate change will impact: that we would have more extreme wind effects. So, yes, we took into account the greater geographical distribution of the generating capacity.

Q11 Lord Krebs: You have already mentioned in your answer to the previous question that you considered the role of carbon capture and storage and of nuclear in the future grid. Could you tell us how you came to a conclusion about the appropriate amount of contribution that these two technologies would make? At the same time, you apparently did not take into account the role of interconnectors. Could you explain why you thought that was not important?

Professor Sir Peter Bruce: Starting with the gas plus CCS question, as I mentioned, we would definitely advocate gas plus CCS being part of the mix for a future GB grid. We have not analysed in detail a scenario where we have a mix of nuclear, gas plus CCS, wind, solar, and hydrogen storage. Why? Because when we looked at this, there are so many uncertainties that the more complexity you build into the solution, the more uncertain the prediction of the best direction of travel.

For that reason, we went back to the base scenario of wind, solar, plus hydrogen, and looked at that against using gas plus CCS as the major generating technology and nuclear as the major generating technology. We concluded from that analysis that, certainly looking at those three more extreme scenarios—wind and solar, plus hydrogen—would be the best way forward. We absolutely support the fact that you need a mixed system, and that mixed system will bring the cost down further, but it would be wrong of me to suggest that we have analysed that in detail. We have not tensioned those in a mixed system.

Lord Krebs: When you say that wind and solar is one in your thinking, was that largely on price?

Professor Sir Peter Bruce: Yes, it was on price, primarily. It was also compared with some of the other alternatives' technology readiness level. Some of the possible storage technologies are not as proven as hydrogen.

Also, on the energy security question, part of the issue with gas plus CCS is that it still leaves us vulnerable to the global gas price, as we have seen in the last couple of years. Electricity has gone from about £45 per megawatt hour to £200 because of the increase in the cost of gas.

The benefits of the wind, solar plus hydrogen solution are that we would own our electrolyzers, we would store our own hydrogen and we would generate electricity from that hydrogen, so we would be much more insulated from the variabilities of availability and therefore of the cost of other sources.

We looked at interconnectors and concluded that perhaps the greatest benefit of interconnectors might actually be our opportunity to export the significant excess wind generation that we have capacity for in the UK to other countries. In terms of securing our own energy supply, again, consulting the Met Office indicated that when we do have periods of low wind, that tends to sit over most of northern European, with anti-cyclones in the winter. So our neighbours will be in a similar position; they will not have that excess generating capacity to supply to us.

So it is a combination of the reality that wind generation will be lower for everyone, and, again, the sense that it does not give us the security of supply that the system of hydrogen plus wind plus solar in the UK would give, because, in every country, every policymaker's and politician's responsibility will, understandably, be to its own citizens, and if we are all suffering a shortage of electricity, I very much doubt that they will give it to us, no matter what agreements are in place.

Lord Krebs: Just to give a minute-by-minute account, as we speak, the contribution of solar and wind is roughly the same as the contribution of interconnectors from Norway, the France and the Netherlands.

Professor Sir Peter Bruce: Yes.

Lord Krebs: It is about 10%.

Professor Sir Peter Bruce: Yes. That is today, but if we look at the next 20 years, France has reduced its generation from nuclear from 74% down to about 50%. Every country is building more wind and solar. I think we will all be struggling with the same problem. I do not think there are countries out there that will not. Maybe Norway is a special case, but the Netherlands, France and Germany will all be struggling with the decarbonisation of our grid systems. Those are our main conclusions.

We would absolutely encourage interconnectors. Again, diversity is a good thing in the energy system. It may allow us to trade energy in a more cost-effective way. We would certainly have an opportunity to export electricity from the significant amount of wind capacity that we have in the UK to our neighbours.

Lord Krebs: Did you leave out tidal energy on costs grounds?

Professor Sir Peter Bruce: Yes.

The Chair: While we are checking what you looked at and did not look at, did you take into account any constraints in the transmission system?

Professor Sir Peter Bruce: We certainly considered this. We have not analysed it, but you are absolutely right. If the proposal is to build hydrogen storage in the salt caverns in Yorkshire, Cheshire and Wessex, in the case of Yorkshire it is a relatively more promising picture because there is quite significant capacity in the transmission system in that area, but it is true that other areas will need grid reinforcement if we are to move that energy along cables—in other words, with electrons.

There is of course an alternative: you could move the hydrogen from the salt cavern stores to turbines located elsewhere in the country, so there is the question of whether you would want to move the energy as hydrogen or as electricity. There is a debate about which is the most cost effective. We allowed, I think, £3 on to the cost of electricity to cover the grid reinforcement. Again, that is something of a guesstimate, I absolutely agree, but we did consider it.

The Chair: Thank you very much.

Q12 **Viscount Hanworth:** Your report concludes that the best technology for long-term energy storage is hydrogen, but I have just come from a

presentation by Frazer-Nash, which proposes storing energy in ammonia generated from hydrogen feedstock that would be created by high-temperature electrolysis, with the energy coming from a nuclear reactor.

It also proposes that something more efficient than the Haber-Bosch process could be deployed in creating the ammonia. I presume that you have also looked at these options. Can you comment on them and tell us why you believe that hydrogen per se, rather than its embodiment in ammonia, is the appropriate way to go, because the ammonia would be easily transportable?

Professor Sir Peter Bruce: You are absolutely right, in the sense that ammonia has the advantage that it is liquified under relatively mild conditions, so the density is high and is more transportable. In all cases, we found that ammonia would add cost to a decarbonised grid. You touched on the reason yourself: with ammonia, you have to make the hydrogen first, and then you make the ammonia. So if you have to make the hydrogen, stick with the hydrogen.

The main case for ammonia for us would be if you wanted to operate storage in very remote areas, perhaps in the north of Scotland, where transporting the power along power lines, or even a hydrogen pipeline, would be an expensive investment. There, it might make some sense to turn the hydrogen into ammonia and then transport the ammonia.

For the salt caverns in the north of England and in Wessex, in pretty much every case the economics has been the thing that has driven the recommendation. The technology readiness has also played a part. Alkaline electrolyzers are a proven technology to convert electricity into hydrogen. There has been hydrogen storage in salt caverns in Texas for 40 years—a bigger salt cavern than anything we are proposing here. Turning hydrogen back into electricity and turbines is a well-established technology.

The availability of the technology, the technology readiness level, and the fact that, in our analysis, it came out as the lowest cost option are reasons why hydrogen is the main solution.

Viscount Hanworth: Can I make one proposition followed by one question? The proposition is that you need ammonia for shipping, for example. You could not conceive of using hydrogen in maritime applications.

The question I want to ask concerns the energy that would be imparted to the ammonia by the process that created it. Is that not recoverable by the direct combustion of the ammonia and, therefore, the assertion that it is costly to create the ammonia and a dead waste of energy is probably false?

Professor Sir Peter Bruce: I do not think it is. The Haber-Bosch process is a high-temperature process; it is quite energy-intensive in that sense. Let me be clear: if we could find a way of turning nitrogen into ammonia electrochemically, in the way that we can decompose water to hydrogen, that would change things fundamentally. That is a really

important research topic, and people are looking at it. If we could make ammonia by a much more cost-effective low-energy route, that would change things very substantially. I regard that as one of the most important research challenges that faces us in this area.

In our analysis, we did look at ammonia in considerable detail. We have one person on the report who is a very enthusiastic ammonia proponent. Everyone agreed at the end of this that it did not produce the decarbonised grid with the same lower cost that hydrogen would provide.

Viscount Hanworth: The cost of ammonia is, of course, the energy that you have to put into it. If there was plenty of energy coming from nuclear power, presumably that cost could be hugely diminished.

Professor Sir Peter Bruce: The Royal Society produced a report on cogeneration two years ago. We looked quite significantly at using high-temperature heat from nuclear, for example, to produce both hydrogen and ammonia. It circles back, in many ways, to why we are not advocating a huge nuclear build as the solution. The cost of hydrogen storage would have to be at the very top of our estimates, and the cost of nuclear would have to be at the very lowest of the estimates before the two started to overlap. There is still a gap in the cost of decarbonising the grid between a significant amount of baseload from nuclear versus wind, solar and hydrogen.

It is not the hydrogen costs that are the issue. It is actually the generating costs that dominate, because the storage supplies only 14% of the electricity demand. For whatever cost you have for storage, you multiply it by 0.14 to get the contribution to the grid. It is the cost of the generating technology that determines the cost more than anything, and it is the wind and solar—two lower-cost generating technologies—that dominates the cost analysis that we had.

Viscount Hanworth: Thank you.

The Chair: Apart from ammonia, were there other longer-term storage technologies that you considered and ruled out, like mechanical, thermal, or redox flow batteries?

Professor Sir Peter Bruce: Yes, we did. We looked at all of them. We looked at compressed air storage in some detail. Again, we determined that the cost was higher. The other aspect of that is that although compressors and expanders are known technology, compressed air energy storage is still not quite the same TRL level as the solution that we believe is best. We would see it as part of the mix, particularly as part of what I would call medium-generation—in other words, timescales of perhaps several hours, maybe slightly longer—but not for the months and years of storage that we are going to need.

The other thing about compressed air storage is that it generates a lot of heat. If anything, it is a heat management problem, because when you compress air, you generate a lot of heat. You then have to store the heat, because you need it when you allow the air to expand again, otherwise the air cools too much. There is a lot of thermal management around making compressed air storage work in a really efficient manner. Again, it

just did not produce the cost analysis that was attractive in terms of doing the heavy lifting on the large-scale storage.

We looked at redox flow batteries. Again, the cost is significantly higher than the solution that we have proposed, and, in fact, significantly higher than compressed air storage. It is also a technology that is not fully developed. There are commercial systems and there are systems deployed, but it is not a mature technology in the way that, for example, alkaline electrolyzers are. Redox flow may play a role in what I would call the intermediate-duration storage, but it would not solve the problem of those tens—50 or 60—of terawatt hours in a cost-effective way.

The Chair: And pumped hydro is just too small-scale and too expensive.

Professor Sir Peter Bruce: Yes. Pumped hydro has a lot of advantages. It is a well-established technology that works very well and we know how to operate it. But the scale of increasing the pumped hydro in the UK to build another thousand pumped hydro stations would be unthinkable for all sorts of reasons. I can imagine fascinating planning conversations that would take place around the country to get anywhere near the scale of that.

Q13 **Baroness Neville-Jones:** You said earlier that, with wind, solar, and hydrogen, we have a very insulated market and good availability. We have now begun to turn to the question of cost. In the Royal Society report, there are a number of quite big figures. Would you like to elucidate them, please? Could you talk about how you costed what you decided was the sensible option? Also, could you say to what extent we have the kit that we need to develop the domestic hydrogen industry, and, if we do not, can we produce the electrolyzers, or will we have to go elsewhere? Can you talk a bit about how you arrived at your costing, and where there may be hidden obstacles that we need to overcome?

Professor Sir Peter Bruce: Yes, as I said, the main factor that determines the cost of electricity in the decarbonised grid is actually the generating technology that is used. We have been using the projected costs of wind and solar, with a mix of 80% wind and 20% solar, which we looked at to see what the optimum balance would be based on the weather patterns, the amount of generation and the cost. Those are essentially taken from the published government figures on projections for wind and solar, not ours.

You are right that the cost of storage per unit of energy is very high; it is approximately £90 per megawatt hour. However, as I mentioned before, you only need it for 14% of the time. When you add it in to the equation for the total cost, it is a minor factor. You could increase or decrease the cost of storage quite significantly and it would only really perturb, to a relatively small amount, the actual cost of the electricity.

The band that we project for the cost of electricity into the grid, if you were to operate with wind, solar and hydrogen alone, is, if I recall, approximately £50 to £90 per megawatt hour. For the 10 years before 2021, the cost of electricity into the grid was about £45, so it is more expensive now, but every decarbonised solution will cost more. I wish

there were an answer, speaking as someone who pays bills like the rest of us, that would reduce or maintain costs, but that is not realistic.

This certainly produces a cost that is lower than all the alternatives we looked at. In fact, we have been quite cautious in our cost estimates. I mentioned that we put a 20% contingency in for weather pattern changes and that we have added in a contingency for grid reinforcement, et cetera. So I would say that the higher number of £90 is quite a pessimistic number, as it will probably be closer to the lower end of that range.

Baroness Neville-Jones: Does that include initial capital costs?

Professor Sir Peter Bruce: Yes. The point you make about whether we have access to the technology is even more significant. There is no doubt that there is a need for scaling up the business of alkaline electrolyzers. They are available and operating in other countries. In the UK ITM Power, makes and markets electrolyzers. INEOS is also very committed to that; it has electrolysis for making alkaline compounds. It is very interested in, and already looking at, scaling up the area of alkaline electrolyzers. So there are companies in the UK that could expand in this area.

Baroness Neville-Jones: Is that is something that ACRE should be pushing?

Professor Sir Peter Bruce: Yes. It's about signalling the direction of travel to business. It would help if there were a clear signal to the industry that the direction of travel is that we will need large amounts of hydrogen storage. As I said, in almost any realistic scenario—while we could debate the numbers and whether it is 30, 50, 100 terawatt hours; even 30 is a large number—we need to get on with this. If we signal that, there are companies in the UK with the skill sets to expand in this area.

JCB is also looking very intensely at using hydrogen to power its vehicles. It is not using fuel cells—it is using four-stroke engines—so I am sure it would be interested in a larger market scale for converting hydrogen back into electricity. You can also use turbines—that is what the Japanese are going to do to decarbonise; they are going to turn their turbines over to hydrogen. We looked at four-stroke engines and they turned out to be the best choice if you are starting from zero when building an infrastructure to convert hydrogen back to electricity.

There is a definite scope and opportunity for the UK economy. If we make the commitment to hydrogen storage and we signal that, it would be an excellent opportunity for the UK to build its own infrastructure and to supply the world. It is absolutely clear that we will not be the only country to need hydrogen.

Baroness Neville-Jones: Would we be able to do that using green hydrogen as a source, or will we be messing around with fossil fuels?

Professor Sir Peter Bruce: We will still be using gas plus CCS for some time. We looked at 2050 in our analysis, because that is the overarching net-zero target, but most of what we say applies to attempting to do this sooner. The biggest challenge with doing it by 2030 or 2035 is being able

to build the storage on that timescale. We have done too little for too long and I worry that we shall then have to scramble around to try to solve the problem when it's too late. We might be tempted to think, "Well, we already have gas generation, and we're going to need CCS anyway" so let's just do it all with gas and CCS. However, as I said before, our analysis shows that gas plus CCS is a more expensive option although the health of the future UK economy will depend on many things, it will depend crucially on having low-cost and secure electricity. If we lock ourselves into a solution that is suboptimal such as gas plus CCS, and add in with the problem of stranded assets when we later have to transition to a better (storage) solution then we will have committed the UK to more expensive electricity for decades to come, it will be hard for the UK economy to be competitive.

We need to get on with building storage now, however we need to do it right rather than do it fast. I would like right and fast of course—I am as passionate about decarbonisation as anyone—but we should be cautious to avoid suboptimal solutions.

Baroness Neuberger: I have a brief question. Our previous witnesses talked a bit about skills and questioned whether we have the skills to do all this. You have just said that you want to do it right rather than necessarily in a rush. Do we need to think about upskilling, training and education?

The Chair: Can we hold that thought, because it is part of Lord Wei's question.

Q14 **Lord Wei:** I declare my interests as an adviser to Future Planet Capital and to Sweetbridge EMEA, which are both, as groups, investing in or working on new energy storage solutions or energy solutions.

How mature are the various technologies that we are considering here? How confident are we that deploying hydrogen energy storage in the UK is technically feasible?

Professor Sir Peter Bruce: There are potentially better electrolyzers than alkaline electrolyzers, but alkaline electrolyzers are a well proven technology. They are deployed and used in China and other countries to produce green hydrogen from electricity, so this is a well-established technology. Certainly, there are great opportunities for improving the technology and there are other electrolyzers that will come into play later, but it is an available technology.

Storing hydrogen in salt caverns is also a well-established approach to hydrogen storage. I mentioned that there is a large underground storage facility for hydrogen in Texas, which is larger than any of the salt caverns that we have proposed using in the UK. Converting hydrogen back into electricity again can be done by gas turbines or by heat engines, such as four-stroke engines. The turbine technology for converting hydrogen back into electricity is also well-established.

I do not think that there are huge technology risks with this. That is not to say that there are not great opportunities to produce more improved

hydrogen technologies in the future to further reduce costs and improve efficiency—there absolutely are. The scaling up of the supply chain is the more significant challenge—making sure that there is enough build of electrolyzers so that we can start moving forward with the salt cavern storage and start looking at converting turbines from natural gas to hydrogen. That is the issue, rather than the technology risk; the technology risk is relatively low with this approach.

Lord Wei: Talking about risk, what are the safety concerns of storing hydrogen in these caverns? Is there a potential political dimension involving public perception of its safety? Thinking about fracking, although that is a completely different process, would there be environmental concerns that might lead to campaigns that could stop this before it had even begun to get the scale you are talking about?

Professor Sir Peter Bruce: There is no fracking involved at all. The plan is to store in salt caverns. You pump water into the cavern and dissolve the salt in the water to form brine, and then pump the brine out and use the cavern to store hydrogen. You have to dispose of the brine, which is salt water, and obviously one option is to dispose of it in the sea, but that is a relatively low-risk part of the process.

This is much less risky than putting hydrogen into the domestic gas supply. We would not be sending hydrogen to everyone's home; we would be putting it two kilometres beneath the surface in salt caverns. We would be electrolyzing the water at the sites of the salt caverns; in effect a chemical plant, run by chemical engineers in a self-contained area. It would not be distributed into high-density population areas or anything like that.

All energy has some safety risks, but the safety risks for hydrogen used in this sort of scenario are relatively small. Personally, I would be much more comfortable with that than with hydrogen coming into my home.

Lord Wei: So there is no risk that, perhaps because of geological faults or issues with the caverns, any leakages might occur that would go above ground? Are they all sealed? Do you treat them with something?

Professor Sir Peter Bruce: As I said, salt-cavern storage of hydrogen is a technology has been around for many decades. People know how to do it and it does not appear to have created any particular leakage issues.

Q15 **Lord Wei:** Then let us focus on the skilled workforce question, which is going to be key to scaling up. Do we have enough people to hit the target, and what do we need to do to get there?

Professor Sir Peter Bruce: I am sure we do not. There will definitely need to be upskilling of people to operate a decarbonised grid of this nature. That is why it is going to be so important to take a holistic approach. It is no good simply asking businesses to bid to operate salt caverns. Unless they know that electrolyzers are going to be deployed, that there will be turbines using hydrogen and that skilled people will be there to operate these things, it does not make a sensible business case to look at the components of the challenge in isolation.

We need to take a holistic approach to the whole decarbonisation challenge, and part of that is looking at training, skills at all levels, apprenticeships and so on, so that people know how to build and operate these systems. It is true that we need to incentivise an expansion of not only the supply chain but the pipeline of skill provision.

Lord Wei: I think the numbers are something like 3,000 or 4,000. Is that right, or do we think they are much higher?

Professor Sir Peter Bruce: Once these things are operating, they do not require a huge workforce to operate them, but of course at the construction stage that is certainly the case.

- Q16 **Lord Krebs:** I am sorry, Peter, it is me again. In a way, my question builds on some of your comments in response to Baroness Neville-Jones and Lord Wei. My question is about the cost of getting all this going and the fact that one needs some policy incentives and the right market structures to get the investment, which is in fact what you were just saying to Lord Wei. Does the Royal Society report have any thoughts about the possible policy support mechanisms that might be relevant? Is it something like a renewables obligation top-up, contracts for difference, or something novel?

Professor Sir Peter Bruce: We touched on this. We are perhaps straying into British Academy territory, so I shall try not to take on that challenge too comprehensively. To answer your question, the main problem is that there is a need for significant up-front capital investment without a return. That is the business model challenge.

It will require investment to build the hydrogen storage infrastructure. It is perhaps similar to building pumped hydro or nuclear, where there is large up-front capital investment; one has to devise mechanisms that will give a return to those companies that take on the challenge. That might mean a guaranteed return on the electricity price or a price floor such that it will not drop below that value, in order to de-risk the up-front investment that they have to make.

We did not come to a conclusion, but we talk about some ways of solving the problem of how to build and operate storage. One can ask whether it should be a national asset, as we are doing now with the rail system. Should we as a country own the storage? We might decide not to operate it ourselves or indeed to build it but we might decide to own it. That is one option. Alternatively, one could have price guarantees for those making the investment in building the technology. Some sort of cap-and-floor mechanism could be enacted too. That challenge is probably greater than the technological one of actually building and deploying this. As I have mentioned several times, we are using relatively mature technologies, but finding the right market mechanism is probably the biggest challenge in making this happen.

- Q17 **Viscount Stansgate:** For the record, I have no financial interests to declare, but it is true that I am president of the Parliamentary and Scientific Committee and a trustee of the Foundation for Science and

Technology. That is on the record. Are there any non-financial issues involved in a grid with large-scale long-duration energy storage that we should be thinking about?

Professor Sir Peter Bruce: Other than the ones we have touched on, I do not think so. As I said, it is mainly about cost, but also about security of supply and the readiness of the technology to be deployed. Those are the three issues that we have principally considered.

We have not ignored safety; we have talked about that already, so I will not rehearse it again. We have looked at the operation of hydrogen storage around the world and its safety record. I do not think there is anything else—apart from finding a way of designing a system that will incentivise people to come forward and actually do it. Is there anything in particular on your mind?

Viscount Stansgate: I asked the question, because I was interested in what you would say. Mention has been made of the transmission system. Are there any potential problems in making that fit for the purpose of transmitting even more energy than before?

Professor Sir Peter Bruce: I do not think there are any technological problems. There is a need to reinforce the grid, with more electric vehicles and so on and the greater use of electricity for heating our homes with heat pumps. For a number of reasons there is a big task ahead in reinforcing the electricity grid system, and this would be in that mix if we decided to transmit the energy principally along cables.

As I mentioned, more work needs to be done on this, there is the question of whether one would want to move the hydrogen from the salt caverns to other locations and where we would site the turbines and convert hydrogen back into electricity. If we did that at the location of the salt caverns, there would have to be a robust grid taking significant amounts of energy from that location into the other parts of the grid.

As I said, East Yorkshire looks like quite a good bet, as it already has methane-based natural gas generators there feeding the grid system. So we would be replacing gas with something else needing broadly the same grid capacity. I am not suggesting that it is quite as simple as that, but there are places where it would be a lot easier to do this than others.

Viscount Stansgate: Can I ask about the small-scale feeding in of electricity? Will the grid be capable of adapting to that in future?

Professor Sir Peter Bruce: Do you mean small-scale in terms of small-scale hydrogen storage?

Viscount Stansgate: Well, energy.

Professor Sir Peter Bruce: There are feed-in tariffs at the moment if people have excess solar or even wind locally, which play a role.

I mentioned interconnectors. I think there is more of a dynamic there, in as much as there is an opportunity for us to sell electricity to our neighbouring countries, given the significant amount of wind capacity that we have.

The only other area where the consumer might play a role in the future grid is if we have large numbers of electric vehicles. They represent storage capacity in their own right when they are not being used, because they are all powered by lithium batteries. One could conceive of using some of that distributed storage to do some grid balancing. We have looked at that too, and it would certainly help with short-term balancing but not with the long-term challenge where we will have wind deficit, which means having several years in a row when we do not have enough generating capacity to keep the lights on.

Q18 Viscount Stansgate: My final question is about what government action may need to be taken immediately to pave the way for the large-scale energy storage solutions that you have been discussing today.

Professor Sir Peter Bruce: The first thing I would do is to put someone in charge of this problem. Storage has to be looked at holistically. We need to work out a more detailed plan of how that would be done, including producing market incentives for the private sector to come forward, build the various parts of this system and perhaps also operate it, so it needs a sensible incentivisation model.

To recap. First, put someone in charge of producing a blueprint for storage. Secondly, it needs clear signalling that this is where we are going as a country and then to stick to it. The disaster for business is when we keep changing our minds. That does not encourage businesses to invest. Thirdly, we need to produce a proper incentivisation scheme to encourage those businesses to come forward and build the capacity. Those are the three main things that I would say need to happen.

More than anything, we need to get going on this, because we have waited too long already. The headline solution in the report—wind, solar and hydrogen—is really more of an extreme example of what could be done. I am not advocating that, and nor is the Royal Society. We are saying that it will be a mixed system. We will have gas plus CCS and nuclear, but a lot of the heavy lifting, whatever scenario one considers for the future decarbonised grid, will require large amounts of long-term energy storage, and that really has to be some kind of chemical fuel.

The Chair: Our previous witnesses were a bit less optimistic about the maturity of the technology than you are. They felt that large-scale demonstration was something that we should be getting on with. Given that you were talking about alkaline electrolyzers, can we in fact just get going at scale?

Professor Sir Peter Bruce: My comments were in the context of the alternatives. I am not suggesting that it is off the shelf in quite that way, but compared with all the alternatives, it is more mature. All the elements are there. As I mentioned, alkaline fuel cells are commercial technology, although we have not deployed them at scale in the UK, and salt cavern storage has been around for decades.

I would want to build a demonstrator, not to say “Oh my goodness, will this work?” but more to learn what we need to do when we come to scale it—learning by doing—because if we produce a demonstrator, we will

understand at a more granular level some of the things that we need to head off when we try to scale it to a greater degree.

The Chair: Do we have some little salt caverns that we could do that with?

Professor Sir Peter Bruce: Yes. We are already storing hydrogen in salt caverns—off the north-east coast, if I recall correctly a cluster of three caverns in Teesside operating since 1972

The Chair: I know that you were focusing mainly on 2050, but do you have a sense of the sort of scale of long-term storage that you think we might need for a decarbonised grid by 2035?

Professor Sir Peter Bruce: We have not looked at other timescales and what storage capacity we would need then, so I probably cannot comment in detail. Although I have talked about the need for large amounts of storage, we do not need them on day one, so we could ramp this up over the next time period. We should not fall into the trap of thinking, “Oh my goodness, we need 100 terawatt hours of storage and we can’t achieve it by say 2035 so we need to look elsewhere for sub-optimal solutions”. That would be a mistake. We should start building storage now and then we can gradually transition to a more decarbonised approach that will deliver the lowest-cost electricity grid system for the UK compared with the others, and we can do that over a period of time. I wish we had started earlier and I wish we could go faster than we probably can, but those things should not mean that we do nothing.

The Chair: So 2036, 2037 and 2038 could all be low-wind years.

Professor Sir Peter Bruce: They could. I am a passionate believer in the need to act on climate change; it is the greatest threat that has faced humanity. I would like us to go faster. It will be—how shall I put it?—a very significant challenge to achieve a decarbonised grid by 2030 or 2035, and one that I struggle to see the route to on those timescales.

Q19 **Lord Krebs:** I am looking at a table of UK salt-cavern storage schemes. There are quite a few, as you know, operated by energy companies such as SSE and EDF. How much competition would there be for storage space between those who wanted to store natural gas and those who wanted to store hydrogen?

Professor Sir Peter Bruce: The level of storage that we anticipate does not exhaust all the capacity for storage in salt caverns. We have looked at the capacity that is unused currently—that is, it is currently filled by salt—and it is more than enough. If we decided that we wanted to store larger amounts of methane, there might be some tension there, but we had that gas storage field in the North Sea (Rough) that we then decided to close down. We are not using aquifers; we are specifically using salt caverns where we have depleted the salt as brine. So I do not think that would create a barrier to the hydrogen solution.

Interestingly, there is a company that says that it has a salt cavern in the north-west and it could do this in 10 years. Actually, it could do it in five, but it would take 10, because the economic case for that company

requires it to be able to make use of the brine. That is an incentivisation question: if the company were incentivised, it could technically do it in five years rather than 10. So there are opportunities to speed this process up with the right market incentives.

The Chair: Thank you, Sir Peter. This has been an interesting session, and we appreciate you giving up your time and coming to give evidence to us. As I said, we now have the Royal Society report, but if you think of any other evidence that you have seen which we might find useful, we would be delighted to receive it formally as evidence for the inquiry.