HOUSE OF LORDS

Science and Technology Committee

Corrected oral evidence: The role of batteries and fuel cells in achieving net zero

Tuesday 18 May 2021

10 am

Watch the meeting

Members present: Lord Patel (The Chair); Baroness Blackwood of North Oxford; Viscount Hanworth; Lord Holmes of Richmond; Lord Krebs; Baroness Manningham-Buller; Lord Mitchell; Baroness Rock; Lord Sarfraz; Baroness Sheehan; Baroness Walmsley; Baroness Warwick of Undercliffe.

Evidence Session No. 10 Virtual Proceeding Questions 105 - 120

Witnesses

Nick Winser CBE, Chair, Energy Systems Catapult; Professor Tim Green, Co-Director, Energy Futures Lab, and Deputy Head, Department of Electrical and Electronic Engineering, Imperial College London; Dr Keith MacLean OBE, Director, Providence Policy; Dr Jane Dennett-Thorpe, Deputy Director for Net Zero Transition, Ofgem.

Examination of Witnesses

Nick Winser, Professor Tim Green, Dr Keith MacLean and Dr Jane Dennett-Thorpe.

Q105 **The Chair:** Good morning, everybody, and particularly our witnesses. We are delighted to have you joining us today. This session is immensely important, which is why we are giving extra time, so thank you for taking the extra time to speak to us. When you first speak, can you introduce yourself, so that we get you on the record? Any members of the committee who have not declared their interests, please do so.

I will kick off with the first question. What forecasts do you use, and how do you get the data about electricity demand and electricity generation to 2050, which is the target for total decarbonisation?

Dr Jane Dennett-Thorpe: I am the Deputy Director of Net Zero Transition in Ofgem. We are committed to enabling the net zero transition, to doing so at the lowest cost to consumers, and to ensuring that costs are distributed fairly.

To your question about what forecasts we use, we acknowledge that the future is deeply uncertain. Knowledge and expectations are continually changing. We have to acknowledge that in our decisions, and to enable and reflect that in our approach to regulation. In particular, as a network regulator, we take a flexible and adaptive approach to regulation, so we ensure that our decisions can keep up with the changing circumstances, whether that is in policy decisions or, indeed, in technologies and technology costs. We have built that into the framework of our network price controls. That is the first thing to say. It is not just a view of the future, but explicitly acknowledging that the future will not be quite as we anticipate or think it will be.

In the context of our distribution price controls, for example, we have asked industry to consider electricity demand using a range of net-zero-compatible scenarios and to plan accordingly. We have pointed them to both the National Grid's *Future Energy Scenarios* and the Committee on Climate Change scenarios, and asked them to plan around what is needed in light of those, so bringing forward investment that we know is needed and making the case for strategic investment in other places.

In our own regulatory decisions, our approach is to think about their impact on the possible trajectories to net zero. It is not just picking a pathway and measuring our impact against that, but thinking about the wide range of implications.

The Chair: Do you have a figure? What will be the demand compared to generation 10 years from now?

Dr Jane Dennett-Thorpe: We do not have a figure. We are not the system planner. As I say, we are encouraging the network companies to look at the trajectories to net zero. In particular, in light of the Government's acceptance of the recommendations of the sixth carbon budget, we need to think about what that says. At the moment, for

example, the CCC says that, to reach that, we need an almost entirely decarbonised electricity system by 2035, which frames the challenge for all of us.

Nick Winser: I am Chair of the Energy Systems Catapult. In looking at this question, we try to model the whole energy system on something called ESME. We also work closely with Ofgem's and National Grid's numbers, so there is quite a lot of joining-up. For a net zero system, we certainly anticipate that electricity demand will approximately double from 300 terawatt hours, which is what it is today, to 600 terawatt hours. Putting numbers on it in that way is bold stuff, but it is very important to put some numbers on the table so that we can think about what that means.

To double electricity demand through the electrification of vehicles, and with a lot of heat pumps clearly being part of the answer to domestic heating, raises some very serious issues for the electricity system, and not just in terms of having to shift twice as much energy through it. If you put all domestic heating on to electricity, the current level of demand might be up by three or more times. That means that you really have to get the absolute maximum out of the existing infrastructure, because building a system that is three or four times as big is enormously expensive and very time-consuming.

That means that the role of storage is a critical topic for this House of Lords Select Committee. It is not just the aggregate amount of energy that needs to pass through the system in a year, but the peakiness of it and trying to flatten the load curve so that we maximise use of those transmission and distribution assets.

On the second part of the question, we expect that offshore wind will play a central role in the transition, supported by other renewables but with a range of storage and flexibility solutions. Baseload is an important thing to think about in all this. That fits into today's discussion, because the more we can move towards smart grids, with lots of flexible storage features in them, and with storage and flexible demand, the less baseload we will need. Baseload, as you know, is likely to come from carbon capture and storage, nuclear and possibly some biomass, but we see that as all adding to the cost of bills.

In the context of today's discussion, it is important to really understand what we can do to create a smart grid with lots of storage in it that replaces the inherent storage in fossil fuels, so that we can power people's homes and vehicles but also minimise the amount of baseload capability that needs to be put on the grid.

Professor Tim Green: Good morning. I am Co-Director of the Energy Futures Lab at Imperial College. For our demand estimates, we draw heavily on the Committee on Climate Change. We do our own modelling on how the electric vehicle fleet and heat pumps influence electricity demand, but we come to broadly the same answers: 450 terawatt hours for 2035, and 600 terawatt hours for 2050, which is what Nick just said. We place our focus very strongly on 2035 for electricity, because that is when electricity needs to decarbonise, so we pull in from 2050, and our

focus is on how we gauge the amount of storage and the fleet of generation that we need for 2035.

Turning to the generation side, the UK is blessed with very good resources for wind, offshore wind in particular, so we see a heavily offshore wind-dominated system. The government target is 40 gigawatts of offshore wind by 2030. We think that you need two to two and a half times that for a zero-carbon system, so a very big expansion of offshore wind. There is a role for nuclear, photovoltaics and so forth. Nuclear comes into the picture if it gets substantially cheaper than Hinkley Point C. On top of all that, we need a lot of storage.

Dr Keith MacLean: I spent 20 years with the utility SSE. Since I took early retirement from that, I have been doing quite a lot of research. I chair a number of organisations, including the UK Energy Research Centre. There is always a tremendous focus on discussions on electricity, and it is really important that we understand heat and the impact that will have on the zero-carbon system, because heat demand is very much more difficult to manage across the day and days, and across the year and years.

The storage requirements for heat are absolutely enormous, as are the differences in the consumption of heat between summer and winter. Therefore, it is a really important factor to understand in looking at future demand and how it can be met by different technologies. Wind is very well correlated with heat, for instance, whereas solar is not. The more solar you add to the system, the bigger your imbalance problems become. Those are factors that you come to only if you study the heat component and do not just project forward from what used to happen in the electricity system.

Q106 **Baroness Warwick of Undercliffe:** Good morning, everyone. My question follows on rather naturally from the last comments. We have had the opportunity to see the National Grid *Future Energy Scenarios* report, and the Government's 10-point plan, which highlighted energy storage and flexibility technologies, such as battery electricity storage, as essential for the UK as the proportion of renewable energy generation increases.

What assessment have you made of the extent to which energy storage will be needed to balance generation and demand, and how much of this would involve batteries or fuel cells? Perhaps you could then talk about the UK's ability to deploy them at scale.

Dr Keith MacLean: I will shortly publish a paper on this which I have been doing with colleagues from Birmingham University. We have tried to understand what balancing is currently being provided for the sector, whether by storage or by other means. It is still being done primarily with natural gas, for both electricity and heat. The orders of magnitude are truly enormous. We are using three or four terawatt hours per day of gas storage in order to provide the ramping-up that we need for heat and showers in the morning, balancing the varying need for electricity during the day. That is generally now all being done with natural gas.

We have to understand how to replace that and how we can balance the books in the future. We have looked at a number of potential scenarios for the way demand will develop, and it does not change the orders of magnitude of imbalance that will occur. It is still terawatt hours per day, tens of terawatt hours per season, and over 100 terawatt hours across the year. Therefore, we really need to look at big solutions.

Things like batteries, which are relatively small and have relatively short duration capability, can play a significant role intraday, but we do not believe that they will be suitable for the truly grid-scale challenges. We will need to look at other flexibility options, such as chemical fuels, in order to be able to balance across the longer timescales and at the larger energy. That is not to undermine the importance of batteries or smaller power applications for the short duration, but we just do not believe that they will become suitable at grid scale. There is just a limit on the chemistry and the physics of them.

Professor Tim Green: Keith just made a useful separation between intraday, short-term balancing, and longer, seasonal, balancing. We have done a study on the amount of battery storage, or storage generally, that we foresee on a wind-dominated grid. We see in the order of 300 gigawatt hours, which is about 0.1% of the total energy over the year, in relatively short-term storage. Two-hour batteries seem to be something of a sweet spot. It means that it can do some balancing of short-term variations in load and wind speeds, for instance, over a day. That number comes down if you see more flexibility on the demand side. The smart charging of electric vehicles in particular takes 10% of that out. If you do vehicle to grid, you take another 10% out.

Then there is the issue of storage over the longer term, which Keith alluded to. How do you get through periods of dark, with low wind speeds? Dunkelflaute is a word that is sometimes used. There was a period this year of about 11 days with wind speeds below 20%. For those sorts of things, you need chemical fuel storage, so we think of that in terms of zero-carbon fuels such as hydrogen. Something in the order of 20 to 40 terawatt hours is what we think you will need to get through not a typical winter but a bad, a one-in-10-year winter. That probably equates to about 60 gigawatts of conversion from fuel to electricity, so that could be fuel cells but it could be modified gas turbines burning hydrogen.

Baroness Warwick of Undercliffe: Mr Winser, perhaps you could say a little more about the UK's ability to deploy them at the scale that we are now talking about.

Nick Winser: The scale of it, as far as we are concerned, is set in context by recalling that our historic systems relied on meeting all our demand from energy storage, because that is what fossil fuels are. We should not be shy in thinking about the really serious challenges for storage on the system as we take fossil fuels out. We believe that, looking across the whole of the energy system, somewhere between 200 and 500 gigawatts of storage might be required across all energy vectors. In our scenarios, batteries typically might need to provide 20% to 35%.

Let us put that in context: that is potentially about 50 gigawatts of batteries. That is the size of the current electricity system. It can be met in other ways, although in our view probably not optimally, but that will only be 20% to 35% of the amount of storage needed. As Keith said at the beginning, hot water tanks, the remaining gas storage and using other technologies will all be very important in meeting that.

To the question that you posed directly to me, if you think about the 50 gigawatts of batteries that might be sensible in this world, we know that at the moment there is deployment down at the one-gigawatt level, with plans, some of which may be very early-stage, for about 10 gigawatts, so at the moment we are a long way short of the amount of battery that would be on an optimised grid system.

I support the comment that the more you can switch vehicle charging and perhaps do vehicle to grid, the more you can immediately give out price signals for the switching on and off of heat pumps, as we see heat pumps become dominant in domestic heating. That will be a huge benefit in this balancing and optimising of the system, but it needs some quite sophisticated reworking of the energy markets and a digitalised, advanced energy system, moving a long way from the energy system of the past.

Dr Jane Dennett-Thorpe: I support a lot of what Nick said. Part of the problem of assessing how much energy storage we need, while not undermining the fact that we need a lot of it, is that it is related to how much demand-side response we get and our use of interconnectors. If we can shift demand away from peak times or to times when we have surplus supply from variable renewables, that is moving productive use rather than directly using energy storage. That will be a key part of a low-cost system, as well as using the assets that we might have for other purposes, as Nick said, particularly transport fleets in electric vehicles using the batteries.

Q107 **Baroness Walmsley:** Dr Dennett-Thorpe has led me very nicely on to my question. Given that in future our electricity will be from renewables, what other existing and new technologies are likely to be deployed alongside batteries and fuel cells? What challenges and opportunities will they present for managing the electricity grids? This may be to allow us to match supply to demand or to use the electricity that we have more efficiently, as Mr Winser mentioned earlier. You have mentioned smart grids already. You might also mention interconnectors and heat pumps, but what else is there?

Professor Tim Green: On interconnectors, our connections to Ireland and to the near continent are important, but we have to consider coincident periods of cold weather and low wind speeds. Clearly, that is a very important part of the flexibility, and we use them extensively already.

The role of electrolysers is interesting. We have talked about hydrogen, which implies green hydrogen, but electrolysers would give us another aspect of flexibility, in that we can turn them on and off according to

conditions in the electricity system. We have an enormous problem of co-ordinating that future system with large numbers of distributed batteries and these other resources. The control room of the future that National Grid will run, and the local control rooms of distribution networks, will have an enormous challenge in dealing with much higher volumes of data, and a much more agile and flighty system that it is trying to control. There need to be huge innovations in the decision-support and analysis-support tools to manage all this.

On international trade in zero-carbon fuels, we have stood down quite a lot of gas storage in favour of tankering liquefied natural gas, so liquefied ammonia imports would give us another degree of flexibility.

Nick Winser: Hydrogen is also an opportunity, as people have said, although probably used in large facilities rather than dotted around the network because of the problems of how to create the hydrogen without a carbon footprint. Compressed air and liquid air energy storage look somewhat less likely to me than batteries, although they will, I am sure, have a role.

The benefit of trying to do as much as we can on batteries is that you can locate them at all levels of the grid, and very flexibly from people's homes, as you work up through the grid levels. That not only meets your storage needs but reduces the need to rebuild all the electricity grids. That is a critical part for me. We need to be looking at strategies that minimise the need to rework the whole of our electricity grid, because that will be very hard and very expensive.

Baroness Walmsley: We waste an awful lot of energy. We sometimes pay wind turbine operators not to turn on their turbines. Is there a role for converting that energy into either battery storage or hydrogen via electrolysers?

Nick Winser: Yes.

Baroness Walmsley: Could it be applied at sufficient scale to help the problem?

Nick Winser: This is a complicated economic question, because the alternative is to reinforce the grid to always be able to get best use out of renewables. It would not be right to reinforce the grid so that the renewables can always run, so you have to balance off the economics of installing storage so that you can smooth the flow to fit the grid or building grid. The market and regulators need to get that balance right, and that will drive a significant amount of money.

Dr Keith MacLean: We are thinking very much in an electro-centric world and not thinking about the challenges of heat. We are not going to flatten the curve in heat by encouraging people to use it when it is cheap in the summer and then discouraging them from using it when it is expensive in the winter. The sheer scale of the difference between heat demand in the summer and the winter is two to three times the size of our current electricity system, so it is a really big thing to manage.

Therefore, we need to think quite seriously about alternative ways of prioritising what we are doing. For instance, just to put it out there, why not consider using all the renewables and low-carbon generation such as nuclear to produce a fuel such as hydrogen, and then have hydrogen, just like we have fossil fuels today, as a means of transporting, storing and using electricity when, where and in the amounts that we need it?

In comparison to batteries, the costs are very much lower. Replacing the natural gas storage that we have for a day at the moment would cost between £2 trillion and £4 trillion in batteries. That is using the most current costs of large-scale batteries in America and Australia. Those are just incredible costs. Even on Nick's 50 gigawatts, work out the cost of those. They are very expensive, so we need to think completely differently about how we will manage this balancing act, with inflexible nuclear, variable renewables and very variable demand. We need a buffer in the middle to deal with that, and batteries are too expensive to be that in long-term, high-power applications.

Q108 **Lord Krebs:** I have a question for Tim Green. You talked about periods when the wind does not blow and the sun does not shine, and you took a one-in-10-year winter as an example. I wonder whether, in doing those calculations, you have taken into account the future effects of climate change. My colleagues in Oxford, who are climate modellers, think that these periods of no wind and no sun could become much longer and more extreme in the future, and pose a real problem for the storage of energy.

Professor Tim Green: It is an excellent point. We are in discussion with the Met Office, and there are several universities looking at this. We took a slightly pessimistic view of 15 days of that, rather than the 11 that we saw this year, but the indications are that we have to model climate change and look at what the likelihood is in 2035. I completely agree.

Q109 **Viscount Hanworth:** I should have asked this question before. We have talked about the future demands of electricity for heating and transport, but seem to be missing the future demands for industry. There are things such as the production of hydrogen and ammonia that we have touched upon, but also the production of steel, cement, bricks and synthetic fuels. If we add those in, it seems to me that much more than a doubling of electricity-generating capacity is required. I wonder whether any of the experts have a comment on that.

Professor Tim Green: The decarbonisation of industry through either hydrogen or electricity is extremely important for the industries you mention. I believe that the climate change committee estimate for 2050 includes something like 90 terawatt hours of electricity for industries that have recently electrified. I do not have numbers to argue with that at the moment.

Q110 **Baroness Sheehan:** We have already touched a little on the need for the smart management of costs to consumers and demand across various generation sectors, so I just want to explore that a little further. This question is for Nick first, but if any of the other witnesses want to come

in, please do so.

Does the UK's energy system need to be smart to make best use of batteries, fuel cells and other technologies? Could you also address what progress has been made so far in making the grids smart, and what more needs to be done?

Nick Winser: The system needs to become smart in terms of households and right across the grid. That will be a blend of using much more information, reforming markets and regulation, so that we have a system that is optimised from bottom to top, right across the system. There might be some discussion later on interactions between different vectors. Smart will have a big part in that as well.

This is an enormous transition, as the committee has been hearing, and the role of smart in it will be critical to the economics. We will need to find a way of optimising local sources of generation battery, and demand second by second, in a way that has not been there at all in the past. The implication of not doing so will be to have to spend an awful lot more money reinforcing electricity systems and building a lot more renewables than we would have had to. The system really needs to become smart very quickly.

Looking at progress so far, happily there are some fantastic products and services out there from start-up innovation. These days, if you want to get a car charger fitted to your house, possibly with a battery or a heat pump, there are people out there coming forward with products that allow you to optimise your take of electricity and possibly, in the future, even to flow back into the electricity grid. We are seeing digital products that will respond to real-time market prices and conditions on the grid starting to be developed and proposed. We now need to accelerate that and demonstrate how some of this stuff can work.

Dr Jane Dennett-Thorpe: We totally agree that the future system needs to be smart. It needs to be digitally enabled and to be sending the right signals. As we have heard, we need a system response in very short times and we need to manage the longer-term demand. The smart aspect, on the shorter timescales, is how we ensure that those signals are in place and that we have planned appropriately.

To add a slightly different reflection from Nick, we understand that the benefits in the cost and reliability of the system come mostly from avoided costs of increased generating capacity rather than a reduction in network costs. About 80% of the benefits of a smart, flexible system are about system-wide costs rather than network reinforcement.

Just to be clear, while I agree with Nick that we never want to build networks such that every resource can be used optimally or renewables used at all times, because it is not an economic outcome, we need to recognise that we will require significant upgrades to our electricity networks, to meet the increasing demand on the electricity system that will come from bringing in the other aspects of our energy system that are currently not electrified, such as aspects of heating, for sure, and transport.

Baroness Sheehan: Does anyone have anything to add on the drawbacks of smart systems?

Professor Tim Green: We should note the concerns about cybersecurity as we do this. We place very high reliance on data. I do not wish to argue against what the previous two speakers have said. We need smart, local energy systems. We need those smart services to flow up into the national-scale transmission system. All that is needed, but there will be a much heavier reliance on data and on fast-acting control, so cybersecurity has to be dealt with.

Baroness Sheehan: There is a big issue with the loss of electricity during transmission through the grid. Can smart grids address that loss?

Professor Tim Green: The losses are quite small in transmission, at 2% or 3%, and 5% to 7% in local distribution. Almost exactly a year ago, there were enough renewables on the system to have turned off all the gas-fired generation for a few hours, but it was not possible because we lean on those gas generators to regulate the frequency and the voltage. They were paid to stay on while wind turbines were paid to stay off. In that sense, spilling or forgoing wind that we could have taken is an expense. That sort of loss is something we can deal with through smart.

Q111 **Lord Sarfraz:** We have spoken about this, but I would like to go into a bit more detail on the interactions between the electricity systems and other energy vectors, particularly hydrogen and ammonia, and specifically the challenges with hydrogen, given that the UK does not have large-scale hydrogen infrastructure and that most of the world's hydrogen production is so-called grey hydrogen, not green hydrogen.

Dr Jane Dennett-Thorpe: As we have already been talking about, the energy systems of the future will be really much more intricately and intimately linked. They already are quite linked. We should not forget that gas has a role in generating our electricity as well as in our homes, but, in the future, because of the smart things that we are talking about—bringing aspects of transport into the electricity system and then thinking about using those batteries perhaps in vehicle-to-grid or vehicle-to-home ways—it becomes one set of interlinkages.

You just asked a question about hydrogen. Equally, we have a question about how and where we would use the hydrogen. That is a strategic decision that government is taking, but it is also a technological question. Even if we decide to use it to generate peak electricity, will stationary fuel cells provide the answer?

A lot of policy and technical questions will need to be answered before we get to clarity on where we are going. The system is evolving very rapidly. We are in a stage of accelerating change and that is what we need to keep pace with. Rather than fixing a view of the future now, we need to enable that transition and that change to happen.

Q112 **Lord Sarfraz:** Mr Winser, your catapult has said that the UK will need to create and build an entire new energy sector within 30 years, to deliver the energy volumes needed for the power sector today using hydrogen.

That sounds like a massive undertaking. Are you optimistic?

Nick Winser: Hydrogen possibly has a key role in heavy goods vehicles—that is a very good use of hydrogen—and, as we touched on earlier, industrial decarbonisation. Hydrogen lends itself very well to major centres of industry that are energy intensive and moving on to some electricity but certainly hydrogen.

I advocate that, because creating a big facility for electrolysis that could create hydrogen could be done at an industrial centre. If you were reforming methane, it is easier to capture the carbon dioxide for hydrogen. Hydrogen has some potential application in domestic heating, but I lean towards the view that a lot of work in that sector will be done with heat pumps.

We might see hybrid heat pumps, which are heat pumps where you can add some peaking capacity with hydrogen or gas, so there is an interaction at the domestic end, potentially; and interactions at the production end, because nuclear can create both electricity and hydrogen, as you could with CCS.

Q113 **Lord Sarfraz:** Finally, would any witnesses like to talk about ammonia? We heard previously about the opportunity. Would anyone be able to go into a bit more detail about ammonia versus hydrogen?

Professor Tim Green: The attraction of ammonia, as you may have heard, is that it is quite readily liquefied and pressurised to a reasonably high density, so it works well in tankers and pipelines. That seems to be the attraction. As an interseasonal or even an interyear store of a chemical fuel, it is maybe more attractive than hydrogen. You are running a Haber-Bosch process using hydrogen from an electrolyser and an electrically driven conversion with nitrogen from air separation, so there is some energy input there in order to buy you the advantages of it being easier to store and to transport. It looks interesting, particularly for international trade in zero-carbon fuel.

The Chair: We have heard a lot of ifs, buts and imponderables, and "We can do it. Maybe we should do it". How sure can we be as a country that we can do all this and meet the target by 2050?

Professor Tim Green: It is even more terrifying, in a way. I take Keith's point that it is not all about electricity, but for electricity we have to do most of this by 2035. It is an enormous build rate of batteries. Nick's figure is 60 gigawatts of batteries, and we think it could be even higher than that, plus the build rates of offshore wind. We really need to mobilise. Those are two technologies. Wind is already deploying quickly. We can maybe supplement it with some nuclear.

Batteries are being pulled forward by electric vehicles and other applications, so the costs are coming down and the production facilities are going up. We have to get on top of the smart aspects—the enabling demand-side response and the changing of the grid operations so that we do not rely on gas generators to provide all the control system—very quickly now.

Dr Keith MacLean: It is a very important point. We really need to make a start on some of these things, and not just wait and hope that something else will come along and save us. We will, no doubt, make some mistakes and regret some of the actions, but we will regret it far more if we do not start making progress now.

We need to accelerate the demonstration programmes that there are for a lot of these things, and to do it in a far more collaborative manner. Generally, if you do things more collaboratively, it is much quicker than if you do try to do it with competitions. Competitions raise all sorts of design challenges. As we have seen from carbon capture and storage, with numerous competitions, we have made no progress at all. We need a much clearer commitment from the Treasury to the funding of all this. We still await the net zero review to see whether there really is the commitment from Treasury to the necessary funding, wherever that will come from.

Q114 **Baroness Rock:** My question relates to demonstration projects, which Mr Winser touched on earlier. We know that there are numerous projects in the UK that will or do utilise battery and fuel cell technologies. Which demonstration projects are testing newer battery and fuel cell technologies? We know about some of the notable projects in Oxford, Orkney and West Sussex. What are the timelines for those projects?

Nick Winser: You touched on the Oxford, West Sussex and Orkney projects, which parade under the banner of the Prospering from the Energy Revolution work, in which I have to declare a slight interest in that I chair the advisory panel on that. They are all looking at more advanced battery types. Energy Superhub Oxford has a lithium ion and vanadium flow hybrid. I am not going to pretend that I understand that technology, but it is a new one.

There is also a project, I am told, at Willenhall: a two-megawatt battery energy storage demonstrator. Other panellists may be able to give greater detail, but I believe it uses lithium titanate. We are seeing some demonstration of some of these technologies. The Faraday Institution is also working on a more advanced next-generation type of battery.

Dr Jane Dennett-Thorpe: I am not aware that Ofgem's network funding is funding any ground-breaking demonstrators at the moment, but I might write to you if that is incorrect. I know that, in the past, we have funded demonstrators. For example, the Low Carbon Networks Fund at the time supported in Leighton Buzzard what was the biggest grid-scale battery-store facility, and those technologies are now more widely deployed, but what was ground-breaking no longer is so. That is the point of innovation.

To address Keith's point about collaboration versus competition, we have redesigned the innovation funds associated with the network price controls to focus on the strategic challenges that we anticipate, in particular with smart, as we have talked about, and how to bring forward ideas, technologies, business models and the wider things around those technologies into the system.

Dr Keith MacLean: I would just support what the others have said. I do not have anything to add.

Professor Tim Green: There is this very interesting point that batteries as a concept have been demonstrated and are now deploying. It is only about a gigawatt connected at the moment, but that is a fast-growing number. The concept that batteries can provide very useful services into electricity systems is well established now. Some of it then moves into the domain of industrial research to see if there is a cost or performance advantage of one technology over another.

Dr Jane Dennett-Thorpe: One of the areas for innovation—that is why I referenced business models—is potentially how to use what you might consider to be the distributed national battery of an EV fleet in a way that benefits consumers and delivers system benefits. That is quite a different model and has different technologies behind it as well. We are in the foothills there.

Q115 **Lord Mitchell:** My question is very simple. Where in the UK are batteries and fuel cells currently being deployed at large scale on the electricity grid?

Dr Keith MacLean: It depends on the definition of "large scale", and perhaps from my previous comments you will gather that I tend not to see batteries really being large scale. Where they are being deployed on the grid at the moment, as Professor Green was saying earlier, is for frequency response. Some have contracts for providing capacity, but that is very limited because the duration simply is not there to provide capacity for long enough for grid services. There are some areas where they are being deployed in a commercial sense without the need for support.

With fuel cells, it is still more limited. We see very few fuel cell vehicles and very little in the way of fuel cell deployment in other applications, other than perhaps in some heating applications, where there is a use for the heat as well as for the power. Neither is at the scale at the moment where it will register on the same picture as the truly grid-scale facilities that we currently have from natural gas.

Dr Jane Dennett-Thorpe: Echoing what Keith just said, at the moment most grid-scale batteries are on the distribution network, providing some flexibility services or frequency response services. We have a gigawatt of batteries currently connected at that level, which is a relatively long way off from the 50 gigawatts floated earlier. In addition, we are beginning to see the start of aggregators being able to access and aggregate smaller installations to provide those services. Again, these are very early days.

Nick Winser: I would reflect that most of the applications at the moment are, at an individual level, quite small. To answer your point in a different way, the large-scale deployment might well be an aggregation of lots of batteries on people's garage walls, where they have fitted charging for electric cars. We are seeing a lot of commercial activity in putting wall-mounted batteries deep down in the grid system.

I draw attention to that, because this is very important. The grid will, at all levels, come under immense strain as we see the deployment of heat pumps and domestic car charging. That will not be the only thing, but there will be quite a lot of domestic car charging. So to have an ability at the domestic level that can play into the market of a big aggregation of domestic batteries will be very valuable.

Professor Tim Green: I strongly support Nick's last point. There is a role for megawatt-scale batteries—hundreds of megawatts—but the kilowatt-scale domestic batteries provide an additional service, which is to take some of the stress off a local distribution network. There is value in that, and that is part of the reason why we see it deploy in our models.

Fuel cells are still quite niche. Fuel cell vehicle sales are still very small compared with battery electric vehicles. The only widespread application that I know of is back-up generation for mobile telecom masts in remote locations.

Lord Mitchell: If I pick up the tone of the answer, it is that it is still small compared with the major problem. One of the words I have picked up from what the witnesses have been saying today is "massive": massive investment, massive infrastructure. May I ask you a question? You may not want to answer it but, in your heart of hearts, do you think we will hit our zero target by 2050?

Dr Keith MacLean: At the current pace, no. We need to significantly up the pace. Without that happening very quickly, the chances of hitting the targets are very low.

Nick Winser: There is currently, as well remarked, a gap between the size of the promises and the policy that is in place to support those promises. That is not a criticism particularly, but something that needs to be addressed very quickly. We need policy support.

A lot of the focus continues to be, rightly in some senses, on deployment of renewables, nuclear and CCS—the principal technologies. The bit that remains a Cinderella, in my view, is the smarts, because they will be so important to this. There is a real danger that, even if we make enough progress on the big technology items, we will not get anywhere near the potential economics of a system that is optimised by smart grids and smart homes, and really great markets that enable all this to be optimised.

Q116 **Lord Krebs:** How will we get to large-scale deployment of batteries and fuel cells for the grid? We have heard that we are quite a bit off course for that. What is needed by way of research, supply chains and manufacturing capacity? Does it need to be in the UK, and are we supporting the sector sufficiently?

Just to give some context, in the evidence that we have heard so far we have been told that the UK has a supply chain and manufacturing capability for fuel cells, for example through Johnson Matthey, but we do not have the capacity to produce hydrogen. When it comes to batteries, we heard strong support particularly from academics for the Faraday

battery challenge initiative, but we were also told that that is very focused on vehicles, not grid applications, and that the technologies might be rather different in grid applications.

We also heard in evidence that the UK may not have the skills or the supply of materials and components to scale up the manufacture of batteries. That is the context for the challenges of research and innovation to meet the challenges that you have talked about.

Nick Winser: A number of things are required. One that has not been mentioned yet in this session is that local-area energy planning is critical to all this. As we try to get to a decarbonised system, there are different opportunities in each part of our geography. There may be ways to heat, there may be industrial processes or there may be an opportunity to produce hydrogen at scale, so we must get to local-area planning to complement our historic top-down planning.

That will be very important. You see that going on quite a lot across the system, for example with plans that have come forward for Leeds and hydrogen, but we need to piece that together. We need sufficient markets that will demonstrate to investors that there are price differentials that make investing in storage viable. That is what will drive investment: if people see the opportunity through the markets of making a return. Looking at the design of the markets is very important.

You mentioned supply chains for materials. There is also an issue of skills. There is an issue of taking some of these new technologies and having large-scale demonstrators. One or two on the panel have mentioned that before. The Energy Systems Catapult has a large-scale demonstrator, but we are very keen to make it a large, real-life demonstrator of local technologies and linking up. Those are a few of the things that are needed.

Professor Tim Green: Build rate and supply chain will be very important on the technology side. We have seen wind turbines and the announcements of new factories on Humberside and elsewhere. That is what we now need to see in build rate and enhancement of batteries. I take your point that a lot of it is being propelled by electric vehicles, and the technologies can be a bit different, but they have a lot in common. A lot of the factors driving the cost of batteries down in vehicles greatly assist in grids.

I would mention high-temperature electrolysers for pairing with nuclear plant and other forms of electrolysers that do something with the oxygen evolved at the other terminal. There are lots of things open there for innovation. In the grid-control schemes, we still have a blockage there to get us to a carbon-free grid operation that we need to unlock with some research and development. The UK should be leading in that. The UK is facing these issues early, alongside Ireland, Denmark and a few notable countries. This is an opportunity for the UK to show leadership on climate change but also to develop industries domestically that can export, and we should grab that opportunity.

Dr Keith MacLean: The situation for batteries in grid applications is not that different from that for any storage technology in grid applications. There are uncertain or limited business models for all of them, regardless of whether they are being used in an arbitrage model, storing the energy when it is cheap and then selling it when it is expensive. That is always difficult to do, because it requires big swings in prices happening very regularly.

In the energy market, that is not a very good political ask in order just to get storage to work. Even in some of the grid applications where you are deferring investment, there is only a certain point of deferral that is economic, beyond which it starts making sense to invest more in wire.

There are natural limits to the economic opportunities. At the moment, it is not clear, as it became increasing clear with offshore wind, that there is a commitment to larger deployment. It was only that commitment in the UK and in other countries that allowed companies to get together and work on standardisation and productionising the supply chain, which really started to get the costs down. We need to get a much clearer view of what will be required before that investment and those optimisations can take place.

Q117 **The Chair:** The next question is about safety issues. There are two issues. Have any polls or anything been carried out to assess the views of the public about safety in relation to hydrogen in particular, as well as large-scale batteries? What are the safety risks of batteries and hydrogen?

Professor Tim Green: I do not have deep knowledge on this question, so I will keep my remarks brief. There is a lot of work on the fire risk in batteries. It was a risk in early lithium cells. It has been largely addressed for aerospace applications and in electric vehicles. Proper thermal management seems to mitigate that risk very well, and that has now diminished in the public perception, appropriately so. I will not talk about the risks of hydrogen; I do not have specialist knowledge on that.

Dr Keith MacLean: I have been working on a number of projects where this has been a big issue. It is important to understand that energy storage and transportation always involve risks. This is nothing new. It needs to be managed for batteries and for hydrogen, just as it needs to be managed for natural gas or other fuels. Natural gas is just as flammable and we have managed that successfully.

Another thing to think about with hydrogen is that it was 50% of town gas, which was used for more than a century until the 1960s and 1970s, before it was replaced with natural gas. We had 50% hydrogen in our homes for heating or cooking, and that was in the days of still much leakier pipes and before the major investment that there has been in tightening up the leakage standards on the gas network.

There is a lot of work going on at the moment in a number of projects, including Hy4Heat, whose advisory board I sit on. H21 and H100 are looking at the deployment of hydrogen in buildings. As part of those, a lot of comparative safety work has been carried out to look at the relative

risks of hydrogen compared to natural gas. The target—and there is a good prospect of this—is that the risks of hydrogen being used in these networks and supplying buildings will be no more than and certainly should be less than that of current natural gas.

Dr Jane Dennett-Thorpe: Safety is not an issue for Ofgem particularly. Keith has already talked about some of the network-related hydrogen projects that we have had a role in funding through the network innovation competition. I just wanted to reflect, as I was listening to the answers, that the issues are not necessarily with the technology itself but with the interface between where and how the technology is being used, and for what purpose. That has been a subject of our previous conversations: there is potentially a difference between it being used in transport, in homes or in industry.

The Chair: What about the public perception of safety? We had written evidence that the Irish public are concerned about large-scale batteries being deployed or stored near residential areas.

Dr Keith MacLean: Regardless of how energy is being stored, there are potential risks associated with that. If you have a gas storage facility, there are very strict regulations about how it is stored, how close it can be to homes and what measures need to be taken, and similarly for other fossil fuels in the past. Therefore, it is correct that an eye is cast over how batteries are located and what safety measures are put in place, in order to reduce and manage any associated risks. It will never be zero risk, but it needs to be a manageable one.

The Chair: We have regulations, as you quite rightly pointed out, in relation to gas but not in relation to large-scale batteries and where they are sited. Is that correct?

Dr Keith MacLean: I am not aware of any, but I would be surprised if they are not forthcoming. It would seem an omission.

Q118 **Viscount Hanworth:** It seems to me that the market signals do not currently provide strong enough incentives to adopt the new technologies at the scale and pace required to meet our 2050 targets. How should the development and deployment of these technologies be financed? Who will ultimately pay for them?

Dr Keith MacLean: There is a big question there about what it is that we are trying to do. Where is the money coming from and who will pay for it? We do not have a clear idea of that yet, which makes it very difficult for financiers to come forward to put money behind these things. It is a bit like the example I gave earlier of offshore wind. Until there is a clear belief in the commitment to do these things, the private sector will not come forward and make the necessary investment.

Nick mentioned earlier that there is still a very big gap between the rhetoric and the targets that we are setting, and the policy that is in place in order to do this. I also mentioned earlier that there are a lot of people looking to the Treasury's assessment of zero carbon and the outcome of that. If there is not the belief that the Treasury is behind it and will

facilitate the necessary resources within the departments that are involved in delivering net zero, it will be very difficult to get the private sector to become involved.

Viscount Hanworth: Do you draw any lessons from our failure to finance a nuclear revival?

Dr Keith MacLean: I would draw lessons from our failures in a number of areas. My own personal experience was in CCS. From the middle of the 2000s onwards, we had a CCS project with BP at Peterhead. That got quite far, and then the Government of the day decided that they did not want to go ahead with gas capture and wanted to go ahead with coal instead. We got on to the second one, and that failed as well, with the Chancellor pulling the funding on it.

These are examples that people in business look at and ask, "Is there a credible story behind all this to encourage us to make these investments?" For me, CCS was one of the ones that absolutely ruined the credibility, so the Government are now starting not from scratch but from behind the starting line, because of the scepticism they have engendered through their previous activities.

I would add to that the pulling of money from energy efficiency projects and other stop-starts as we have gone through. It is not a good background picture. I will add a positive one: the work that was done on contracts for difference and putting in a contractual arrangement found a way of satisfying the investment committees in private companies' boards.

Viscount Hanworth: It seems we are talking of a general pathology.

Nick Winser: There are five quick points on financing. In terms of batteries and other storage technologies, understanding the market opportunity is hugely important to investors. That means that a lot of the modelling and commentary is very important and needs to be supported.

In terms of getting deployment, ultimately getting proper price signals set at all points of the system will be very important. Some market reform to make sure that when renewables are plentiful the price drops and when they are not the price rises is what will drive some of these storage technologies.

In terms of developing the technologies, public sector funding needs to come in, in two places: as usual, in early technologies and in supporting things such as the Faraday Institution, which was mentioned earlier. They are looking at next-generation batteries and getting some support on that. There is a great opportunity for the UK to get a leadership role, if we try to leapfrog ahead of the current generation of batteries.

Public sector money also needs to flow into the demonstration of how these things perform on the system and integrate into the system in the future. Private money will then come into the deployment phase.

Professor Tim Green: I would reinforce the points about market signals signalling the way forward. The National Grid Electricity System Operator is also good at signposting where it thinks it will need new services that

batteries and other technologies might bring forward. It does that in a technology-neutral frame, but it is good at pointing out future business opportunities.

It is not so clear for local energy systems and the way distribution networks may need to procure services from batteries and other technologies. We need something akin to the Faraday Institution that addresses the system operation and smart grid technologies that really propel that forward. That is on the point of holding us up in the next stage of getting the last bit of carbon out of the electricity grid.

Viscount Hanworth: Jane, when you were talking about smart in general, were you talking primarily about smart consumers or smart machines? What is the balance there?

Dr Jane Dennett-Thorpe: There is a role for everything. I do not think we can rely on consumers changing their behaviours. It would not be effective. There is a range of different ways in which we need the system to be smart in different places. As Tim was alluding to, there are elements of it that are embedded within the network system and the energy system. Even in consumers' homes, imagining that consumers will need to be twiddling with knobs is probably not the way we need to think of the future smart system.

There was a question earlier that I may return to, which is on concerns about smart. One of them is to make sure that we set up the smart system in such a way that its benefits are distributed appropriately and fairly across consumers. There may be groups that find it more difficult or do not have access to the technologies that are smart and who therefore are not benefiting from this transition. We will need to keep an eye on that.

Broadly, I agree with the previous witnesses, in particular on the need to provide clearer, more granular signals as to where we need flexibility and storage to play a role.

Q119 **Baroness Blackwood of North Oxford:** Professor Green made a very clear statement that we need to mobilise an enormous build rate in order to meet these exceptionally ambitious targets, which Nick Winser has clarified for us in a very stark way. I would like to understand what recommendations on policy and regulatory changes the committee could make that would send the necessary signals to facilitate the deployment of the technologies that we have been discussing at scale, in order to meet these targets. We are not going to meet them without those very strong regulatory and policy signals.

Dr Jane Dennett-Thorpe: I would exactly underline that. In particular, it is not just about 2050. Getting to 2035, which people have talked about, with a broadly net zero electricity system is a particular challenge. We need a different system in the future and, therefore, we will need different policy and regulatory approaches to get there. We have just been touching on that. One is clarity of direction and the other is about ensuring that the market is providing the right signals.

At Ofgem, we have put full-chain flexibility as one of our five strategic priorities, to make sure that we are leaning as heavily as we can to make that a reality. Within that, signals are one, to make sure that we are incentivising those behaviours and unlocking the investment. Another is to look at the behaviours, and to understand what different users need from the system and how they will respond to the different incentives or nudges that we put in place to deliver those. The final one has been touched on by Tim and is about system planning and operation. How are we going to embed the right institutions, tools and decision-making within the system to deliver that?

We do not have the answers, but we need to accelerate this transition. The net zero target has brought forward a 2050 zero-carbon electricity system to 2035, so the pace of the change has become much faster.

Baroness Blackwood of North Oxford: Nick, given the scale of the challenge, we will need to get those answers quite quickly. Could you suggest some specific proposals regarding regulatory and policy changes that would accelerate that change, maybe learning lessons from things that have not worked so well in the past?

Nick Winser: I would focus on four things. First, reforming the markets to give price signals that are accurate in very short timescales, second by second, and at different locations on the system is very important. We are prisoners of the past in having market systems that are, essentially, about wholesale. We need to have wholesale and retail markets, which then signal strongly to investors in batteries and other technologies.

The second is joining it all up. System integration and making this all come together is, as Tim said, quite likely to become one of the key blockers. We need to find an institutional framework where the industry and policymakers come together in a very powerful way to see what the future is and to plan out regulatory and market changes.

Thirdly, let us focus on the local. The local continues to be ignored and will very important in all this, because we will have diverse, multi-vector, interactive energy systems, where the local needs to be focused on.

To support that, fourthly, we need to focus on information and digital resources, because most commentators see that there are great efficiencies as we convert to a decarbonised system, if we can get a lot more information and use it a lot more wisely to optimise the system in a very different energy world.

Baroness Blackwood of North Oxford: Professor Green, you flagged this as a matter of urgency. What would your views be? Do you agree on the need for a horizon-scanning group?

Professor Tim Green: I do, particularly on the joining-up issue. We have a lot of work to do on that. BEIS could swing behind that and fund a programme of fundamental research on the grid operations, as well as joining-up and demonstration projects, but with a broad industry stakeholder group that directs that, because it is a system issue.

The setting of the 40 gigawatt offshore-wind target was very helpful. I would argue that it is still not ambitious enough for 2035, but could we look to do something similar on storage? We know that storage will be important. We might argue about the exact volume but, if we could make a statement about some perceived minimum volume, that would give a very clear signal. We need forward-looking market reforms. Rather than reacting to market deficiencies, we should look at what the markets need to be, particularly for local energy systems of the future, as Nick said.

On hydrogen, there is quite a lively debate about what the hierarchy is: what are the most important uses of hydrogen and what falls towards the bottom? Aviation and industry decarbonisation are somewhere towards the top, and other things towards the bottom. We need to formulate and publicise that strategy.

Dr Keith MacLean: I would just add the truism that we would not be doing this if it was not for the zero-carbon target. We have enormous amounts of storage in the system at the moment, and have had for decades and centuries. The problem is that that is almost free. There is no cost associated with it, so bringing in something that will be very expensive, such as battery storage, is difficult because it is competing against something that, at the moment, is very cheap.

The area where batteries are making good headway at the moment is in vehicle batteries, and that is partly because we have a very strong proxy carbon price through the fuel price and all the taxes on fuel, which means that alternatives such as batteries or hydrogen are not that far off. In other parts of the system, such as heat, we are miles off. If batteries are 10,000 times more expensive than natural gas storage, there is a mountain to climb through any sort of regulatory or policy tool. We need to just recognise that.

If that is the challenge and what we want to do, and if we will try to do it with batteries, we need to recognise that we need to spend 10,000 times more on each unit of storage than we do at the moment. That is why we still need to consider alternative chemical fuels in this and to get the balance right between the short-term, lower-power applications for which batteries are extremely well suited, and other high-power solutions for the longer term, where at the moment it is difficult to see, even with regulatory intervention, how an economic case can be made.

Baroness Blackwood of North Oxford: Based on the previous interventions, none of you has said what we absolutely should not do, what lessons we should learn and what unintended consequences we should try to avoid. I know that there have been some successful interventions but also some failures. Could you name one thing: "Please do not do this again"?

Dr Keith MacLean: Most of the incentive-based approaches that we have taken have fallen far short on delivery and have done the opposite in terms of the cost. Things such as the Renewable Heat Incentive have made pitiful progress but have cost us an enormous amount of money. Things that have worked well have generally been regulatory interventions such as the Clean Air Act and the regulations that made it

necessary to install condensing boilers. There was no choice in that. Those worked well. The incentive-based schemes have worked less well and have added to uncertainty, because they tend to be start-stop.

Q120 **Baroness Manningham-Buller:** I have a question for Nick Winser. Of your four things that you recommended in reforming markets, the third was on local. Could you expand on that a little so that I understand better the key point you were making? It may have been answered earlier in the evidence session, in which case I apologise.

Nick Winser: The local perspective is very important. It has not really been included in the past design of the energy system and markets, because we converted large amounts of energy a long way away and shipped it in on wires to customers who just took it. We see the need for demand flexibility against price, which in itself is against the availability of renewables. Optimising the use of storage and local generation, and optimising when and where cars are charged, is crucial in how it all comes together. Local optimisation of local generation, storage and demand becomes critical to the system of the future, so we have to start thinking locally as well as nationally and internationally.

Baroness Manningham-Buller: This is presumably also about communication, picking up Lord Patel's question about public concern over the safety of some of these issues. The two go together, do they not?

Nick Winser: Yes, and there is a very positive story there. With local planning and engagement, there is lots of evidence in places such as Orkney that that creates a very positive community-based ownership of the challenge to decarbonise.

The Chair: Thank you very much indeed. Our time is up, and we are bang on time, so can I thank all four of our witnesses most enormously for helping us today? It has been a most informative and educational session for us. If, on reflection, you feel you might have added to some of the answers, please feel free to write in, and we will record that as official evidence. For today, thank you very much. You will get a transcript to look over and, if any corrections are needed, please let us know. Thank you very much indeed for today.