



Select Committee on Science and Technology

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

Tuesday 23 March 2021

11 am

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Members present: Lord Patel (The Chair); Baroness Blackwood of North Oxford; Lord Kakkar; Lord Krebs; Baroness Manningham-Buller; Lord Mitchell; Baroness Rock; Lord Sarfraz; Baroness Sheehan; Baroness Walmsley; Lord Winston.

Evidence Session No. 5

Virtual Proceeding

Questions 60 – 69

Witnesses

Professor Philip Taylor, Director, EPSRC Supergen Energy Networks Hub and Pro-Vice Chancellor for Research and Enterprise, University of Bristol; Professor David Greenwood, CEO of the High Value Manufacturing Catapult at Warwick Manufacturing Group (WMG); Director for Industrial Engagement, WMG, and Professor of Advanced Propulsion Systems, University of Warwick; Professor Paul Dodds, Professor of Energy Systems, University College London.

USE OF THE TRANSCRIPT

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

Examination of Witnesses

Professor Philip Taylor, Professor David Greenwood and Professor Paul Dodds.

The Chair: Good morning. Thank you for helping us with our inquiry today; we much appreciate it. I ask Committee members and our witnesses to be brief in their answers, because I have to manage the time to about seven to eight minutes per question.

Q60 **Lord Mitchell:** I—like everyone else, I am sure—am trying to get a handle on where the UK stands in the world with respect to battery and fuel cell research and development. Which aspects of battery and fuel cell research are we focusing on in this country? What have been the major influences for the past 20 years that have led to where we are today? Is the current R&D activity focused on lower TRL-level research or demonstration projects, and do we have enough demonstration projects?

Professor David Greenwood: On the balance between the battery and fuel cell research and development, I think this echoes the tail end of the comments that I heard in the previous session: the UK has much stronger and better funded activity on batteries at the moment than it does on fuel cells. The balance on batteries at the moment is actually quite reasonable between the early stage, early-TRL university research, which tends to focus predominantly on chemistry and materials with some Innovate UK-type activities to help companies to look at the innovation piece, and things like the automotive transformation fund, which looks at the commercialisation piece. The Faraday challenge and the activities around it give us a very good mechanism by which to push all those things forward in concert.

You could argue that there are two issues with that at the moment. One is longevity of funding and its visibility over a long period of time. I think I heard Tony speak in the previous session about the fact that this is a five-year to 10-year journey, not a one-year sprint. Unfortunately some of those mechanisms have funding visibility of only one or two years at the moment.

The second issue is probably quantum. If you look at things like the automotive transformation fund, which is there to encourage investment in gigafactories, a single gigafactory requires somewhere between £2.5 billion and £4 billion of investment, but I think the total fund at the moment is around £400 million. Coming back to Lord Krebs' question in the previous session, if you compare that to the scale of what is happening in Europe, we have a little way to go on that.

Professor Paul Dodds: I am professor of energy systems at UCL and I specialise in whole-economy energy system models. I am also a member of the H2FC Supergen hub where I lead on socioeconomics. I would like to take the fuel cell angle to this question.

The data, and by the data I mean the number of patents that have been granted and the number of journal publications produced in this area—I do not have separate data for fuel cells and hydrogen, so I am talking about hydrogen and fuel cells here—tells us that the UK has more or less

followed global trends for the past 20 years. Twenty years ago, when fuel cells were receiving a huge amount of hype, the focus of research and development was very much on developing a cheaper and more reliable product and trying to commercialise it, but that did not happen because the fuel cells were too expensive compared to alternatives.

In the intervening period, great strides have been made. Patent analysis shows that there has been a shift in the last few years from fundamental innovation on fuel cells to system integration—that is, putting fuel cells into things. We have seen a big reduction in the number of patents on fuel cells themselves—the core technology—and a big increase on the integration side. The UK has pretty much followed these international trends.

Investment has been a lot lower in the UK compared to the USA, Japan, Korea and, latterly, China. We have seen that the UK has had far fewer patents granted and far fewer papers published. If you look at the relative number of patents for the UK and the world in this area, you see that the two lines are almost exactly on top of each other; it is quite amazing, actually.

Another thing to note is that the UK has a smaller proportion of journal papers co-authored between academia and industry than, for example, Japan, which might suggest that we might need to link academia and industry together a bit better, which is something that other countries may have done a bit better in the past.

Saying that, the UK has generally not invested in energy technologies at all. It is relatively stronger in hydrogen fuel cells than it is in other energy technologies compared to competitors. It has a talented science base, and the papers that it produces are quite highly cited, although the advantage that we built up in the early 2000s did not continue into the 2010s, so the citations of more recent papers have gone down a bit.

We did a survey of the whole fuel-cell sector in the UK in 2019. We found 20 UK companies involved in fuel cells and another 13 involved in materials. Something that was not discussed much in the last session was that a lot of the focus in the UK is on fuel cell materials and on building stacks rather than end-use products, and that is an area where the UK has some world-leading specialisms. However, there is also a strong engineering integration focus that historically has been a strength of the UK.

Professor Philip Taylor: I am from the University of Bristol where I am the pro-vice-chancellor for research and enterprise, and I am the director of the Supergen energy networks hub.

I want to pick up on the focus part and the demonstration part of the question. In the UK, we have focused on battery technology, predominantly for the automotive sector, in the fundamental material science and development work. Clearly a very important use for battery technology is also in grids to help us with the decarbonisation of our energy networks and energy systems.

In that space, we have been quite good at demonstration. Through Ofgem's low-carbon networks fund we have been able to demonstrate grid-scale energy storage in the UK pretty successfully at large scale to show how it can help to integrate renewable energy, and more work will be required there. We have even developed dedicated markets, such as the enhanced frequency response market, to pull on battery technology at the grid scale.

However, there is a bit of a disjoint between what is happening at the fundamental level with battery technology research and grid requirements. We heard earlier today that a lot of the targets relate to the size, the energy density and the weight. That is because we are thinking predominantly about transport applications, where size and weight really matter. But if you have a stationary grid-scale energy storage application, the requirements for power and energy are quite different and, if it is a bit heavier, that does not really matter so much. If it takes up a larger footprint, that does not matter quite so much either. So a lot of the work needs to start to think about grid applications, grid services and the trade-offs there so that we are not just developing batteries that are small and lightweight, because that is not the primary requirement for grids.

Q61 Baroness Manningham-Buller: I do not know about other committee members, but I am getting a mixed picture of some very substantial success and movement with the Faraday challenge but, at the same time, much less investment than some of our competitors. The last panel was not sure that we should worry too much about competition with others, but I would like to ask where you think we rate in our research into battery and fuel cells compared with other countries.

My second question is: rather than trying to cover the suite of things that could help us to get to net zero, should the UK play to its strengths and seek to specialise, given that we cannot compete on all fronts, given the investment levels? So the first question is how we compare, and the second is whether we should focus or try to cover the lot.

Professor Paul Dodds: Again, I can talk more about fuel cells than about batteries. Historically our competitors have invested far more in fuel cells than we have, particularly in Japan, China and Korea. That is both stationary and for mobility applications—that is, transport. From memory, Japan's micro-CHP programme invested about \$250 million per year over a sustained period just in micro-CHP development and deployment within the market for learning by doing.

I think the UK would struggle to catch up in markets like that. When it comes to designing fuel cell cars, for example, there have been advanced programmes in east Asia in particular, and the UK is unlikely to catch up unless it can produce some sort of revolutionary design. There have been some companies that have been trying that in the UK, notably Riversimple, which is trying to design a fuel cell car from the ground up rather than trying to adapt an existing car to use fuel cells, which is a really interesting approach and actually might be successful.

There are other revolutionary technologies. I think you talked to Nigel Brandon in an earlier session, and Ceres Power is one of the companies that he spun out. That is an example of a UK company that has a quite revolutionary fuel cell technology in terms of making micro-CHP fuel cells cheaper. The Japanese programme has had a very strong focus on the evolution of manufacturing and learning by doing, but the way that Ceres makes fuel cells is quite different and could achieve a substantial cost reduction. However, Ceres needed to go abroad to commercialise. It struggled to get funding within the UK, and in the end it has partnered with a number of overseas countries, particularly in Asia. The UK Government see no role for micro-CHP fuel cells.

My view is that the UK needs to specialise and focus on the small number of areas where it has strengths over its competitors.

Baroness Manningham-Buller: And not try to catch up with others?

Professor Paul Dodds: Not in those areas. I think—

Baroness Manningham-Buller: I would like to give other panel members a chance to see whether they agree with you.

Professor David Greenwood: To answer your question, we have to think about what we are competing for. In answering to the UK taxpayer, I am much more comfortable talking about value creation, job creation, employment, GVA and so on than citations of papers, which are a means to an end. The competition in the battery industry that the UK is looking for is to manufacture the batteries that go into the cars and the grid energy storage that we will be deploying over the next few decades.

We will not really be competing against predominantly Asian manufacturers for that, because the economics and logistics of the battery industry are that you do not want to be manufacturing that product a long way away from where you are manufacturing the vehicles or the grid energy storage. We need to be thinking carefully about what we do to get the industrialisation and commercialisation. That is the real competitive ground that we are in right now.

R&D is an attractor to companies to come to the UK and it helps them to improve their product over time, but actually it is about the immediate market demand and how easy and cost-effective it is to build factories and supply companies here.

That brings me to your point about focus. I would argue that one of the reasons why the Faraday battery challenge has been successful is that it set off with a very clear focus. To begin with, that focus was automotive batteries. To be fair, the automotive battery market is at least a factor of 10 times bigger than the grid energy storage market. Helping the academic communities and the industrial communities and linking into government policy with a very clear aim as to where we wanted to get to, which was the large-scale manufacturing of batteries for cars in the UK, really helped to build the momentum and to get the linkages between universities and between universities, companies and Governments.

If we talk about hydrogen and fuel cells, we need to ask ourselves the same question: where should we be focusing to deliver the best value for the economy? I would say that almost all manufacturers have now stopped looking at fuel cells as a passenger car technology. We still have Toyota and BMW, and Jaguar Land Rover has a research activity in the UK looking at fuel cells, but for most markets it has been judged that that will not be a cost-competitive technology.

Where we are seeing real opportunities is large-scale energy storage and heavy-duty vehicles: things like trucks, trains and marine applications. If we create the same level of focus for the fuel cell sector that we were able to do for the battery sector, there is every reason to believe that we could achieve a similar rate of progress.

Q62 **Baroness Manningham-Buller:** I think you wish to add something, Professor Taylor, so I shall come to you. If there is time, I would also like to ask any member of the panel how we could make the UK more attractive than it is to inward investment.

The Chair: Please answer briefly on the first question and then briefly on the second.

Professor Philip Taylor: On the point about competition, one of the things that we are in competition on internationally is people and skills. The funding in the UK is relatively modest compared to other countries. What is also difficult about it is that things like the Faraday battery challenge are often funded for a short period of time. As you can see, there are many postdoctoral researchers working in that area at the moment, but the funding stops in 2022. There are jobs all over the world for those highly-skilled people to take, so longevity, security and confidence in the funding are really important in order to keep the skills base in the UK.

Professor Paul Dodds: We surveyed hydrogen fuel cell companies a couple of years ago. The European companies in east Asia were seen as having stronger policy support for hydrogen fuel cells while Europe, North America and east Asia were all considered to have better labour with appropriate skills. Those are two areas where we could perhaps improve.

Professor David Greenwood: On the inward investment piece, we have a very good mechanism in place now in the UK, with DIT working with BEIS and others and Defra also engaged now. If you think about what is important for a big company wanting to put a battery factory in the UK, you need about a square kilometre of land and you need that land to be connected to a power supply of 40 or 50 megawatts, so a large-scale power supply.

You need the skills that Professor Taylor talked about. You need 2,000 to 3,000 people in total and a supply chain that is ready to step in and support. The UK Government have put some really good joined-up mechanisms in place to create that offer for companies looking to the UK.

There is one other element that is needed: countries around the world are bidding to get this business landed in their territory, because they

recognise that early investments now will be the nucleus for growth in the future. This is not a level playing field; there are incentives played across the world in different forms, and we need to make sure that we are competitive in that to land the early investments that will grow later.

The aspect of longevity of funding visibility, which Professor Taylor raised, is critical. Industry has to make its business decisions over five-year and 10-year periods for this, so having funding mechanisms that are decided on an annual basis within government does not necessarily give them the longevity to make confident, long-term investments. That clarity over a five-year to 10-year period would actually crowd in private sector investment alongside what government is doing. If we fund it only in short-term sprints, inevitably the level of government support will have to be proportionately higher.

Q63 Lord Krebs: My questions have largely been answered, but I just want to check that I have understood the answers correctly. I wanted to ask how successful our witnesses feel the Faraday battery challenge has been in advancing battery science and applications.

There are two sub-parts to this, which I think I have heard. In terms of the continuity of research funding, all the witnesses agreed, in answer to Baroness Manningham-Buller's question, that it is a problem. We need long-term continuity and we do not have it.

The second part of the question concerns whether the battery challenge is focusing largely on the light vehicle transport sector and what read-across there is to other sectors such as heavy transport or grid storage. I think Professor Taylor commented on that earlier on.

I think you have answered these questions, but this is an opportunity for you to add any further points you would like to make.

Professor Philip Taylor: I would say that the Faraday battery challenge has been very successful in the area that it has focused on, but there is a compelling case for it to look more broadly now and certainly to look further into grid applications. It should be provided with funding to enable it to do so. We are going to need energy storage in our grids more and more as we add more and more renewable energy, to keep our grids stable and secure and to keep the lights on. That is a really important challenge going forward and it can be a fairly straightforward expansion of the role of the Faraday battery challenge. I would certainly recommend that.

Professor David Greenwood: In answer to your question about how good the Faraday challenge is, let me reflect on it in this way. I work with colleagues in America and Germany who have their own national programmes, and they are envious of the way in which the UK has managed to build the connections between universities, and between universities and industries, in a way they have not been able to do. So in terms of the structure of the mechanism, we should be very proud of what has been done.

You are correct in saying that our focus in the Faraday challenge has been light vehicles to begin with. I do not think we should be apologetic about that, because it was that clarity of focus that enabled it to build the momentum that it has in such a relatively short time—remember that it has been running for only about four years in a journey that was originally intended to be at least 10.

The Faraday challenge has already expanded out into working with things such as the aerospace sector, and I think the grid storage sector is the next logical one for it to expand into over time. However, what is important to us as a UK battery community is to keep this centralisation of expertise. The skillsets that you need to develop batteries for these applications are quite similar. If we ended up fragmenting that, in a situation where skills shortages are a major problem, we would be inefficient in the small activities that would take place. So crowding that activity into Faraday would be a good thing.

Professor Paul Dodds: Due to the automotive industry bringing down the costs of batteries, we can now use them for grid-scale storage. People have been looking to re-use batteries that have been in cars for grid-scale storage when they have degraded by a certain amount. That is also a useful thing.

Another area that we might need to think about a lot more is vehicle-to-grid storage in a way that does not overly degrade car battery performances. Essentially, we have a lot of cars sitting on people's drives that could provide energy storage to the system when it is needed, if we could sort out the technology behind that.

- Q64 **Lord Kakkar:** I would like to turn once again to the question of public funding for research. I think we have heard in the previous session and in this that battery research has received substantially more public funding, by a factor of 10, than fuel cell research. If I have understood correctly, the reasons for that are partly due to the natural history of the development of these different technologies, with battery technology being at a more advanced stage earlier and then a better bet for this type of holistic funding. Is that a correct interpretation and does it explain the difference in the rationale for the direction of public funding between batteries and fuel cells?

Professor Philip Taylor: I think your characterisation is true, to a great extent, but I think that things have changed now. We have made a lot of progress with battery technology in the automotive sector for light passenger vehicles. There have been a lot of developments in the broader area of hydrogen and the use of hydrogen to get us to net zero by 2050. The Committee on Climate Change assumed that we will be using around 700 terawatt hours of hydrogen by 2050, so there is a lot of work to do in this space, and a good case could now be made for an equivalent to the Faraday battery challenge but about hydrogen and fuel cells as a partner programme with lots of overlaps and interactions.

- Q65 **Lord Kakkar:** We have heard that providing the necessary focus is one of the reasons why the Faraday battery challenge has been so successful.

Do you now believe that with a focus similar to that in areas such as the heavy-duty vehicle use of fuel cells and energy storage more generally we are in a position to design something that will have the same focus and could therefore deliver in the way the Faraday battery challenge has but in this case for fuel cells?

Professor Philip Taylor: I think you are right. One of the great things about the Faraday battery challenge was that the automotive industry came together really effectively to say that it unanimously wanted this and would engage with it. For a hydrogen or hydrogen and fuel cells initiative of a similar kind, we would need to decide whether it was going to be about heavy goods vehicles, trains, the aviation sector, or a mixture thereof, and test that with industry and decide on the focus or on what the first area of focus might be.

Lord Kakkar: Professor Dodds, do you have a view on that and on how that conversation might be stimulated to deliver a similarly successful programme for fuel cells?

Professor Paul Dodds: I am not sure I would agree totally with Phil on this. We had some thoughts about this a while ago. Fuel cells and battery technologies are to some extent complementary for all vehicles, so all fuel cell cars have batteries in them, for hybrid or plug-in hybrid operation. Nobody designs one without batteries. The question is how many.

Also, a lot of the expertise on fuel cells is very closely linked to batteries, to the extent that a lot of academics will work in one area or the other depending on the current funding landscape; there is quite a lot of switching within the sector. When we came to look at this a couple of years ago, we recommended that we should consider separate hydrogen and electrochemical centres, with the electrochemical centre covering batteries and fuel cells and accounting for the similarities between the two types of technologies.

Lord Kakkar: Professor Greenwood, on the question of how funding incentivises research priorities and how academic teams decide to focus their effort, do you think that, with the Faraday battery challenge having taken the approach that it did—clearly very successfully—there has been a distortion in academic focus in the fuel cell area? If that is indeed the case, have we lost ground as a country and can it be made up?

Professor David Greenwood: First, let me come back to the question you raised at the beginning, which was why batteries seem to have powered ahead and fuel cells have lagged behind a little. There are two critical reasons for that. The first is a massive difference in technological progress. Batteries have reduced in cost to one-tenth of what they were a decade ago, and they have doubled in energy density over the same period, which has meant that they are now capable of serving many of the needs for transport and energy storage applications. Fuel cells have progressed, but they have not done so at quite the same rate.

Applications have become much more clearly defined for batteries, which has allowed the research community to rally around specific targets and

activities. That is why the Faraday has been able to be successful. I therefore echo Professor Taylor in saying that if we want to do the same thing for the fuel cell sector, we need to do two things. The first is that we need a clear policy on where fuel cells will be applied so that the research community can focus on the right outcomes. At the moment, there is no huge clarity on that. We need a hydrogen policy and we should not just assume that transport is the only option. Hydrogen will have a role to play in decarbonisation of heat and probably in seasonal energy storage, so we should not assume that renewable hydrogen will be available to every application that desires it.

Secondly, having got the energy policy in place, we can start to look at the types of products, and their requirements, that will come forward. Then we can focus the research community on answering the right questions. I am not sure that I agree with Professor Dodds that we should have an electrochemistry centre. The Faraday has been successful because of that clarity of purpose and focus. The challenge we had with the academic community prior to that is that we had organised by discipline. We had groups of electrochemists who flexed between fuel cells and batteries according to where the funding calls came.

It is critical that we keep a focus on delivery if we want this rate of progress. I would be absolutely supportive of an equivalent Faraday for fuel cells, but it needs to have an industry to be pulled by, which is a relatively small industry in the UK. It needs to have clear targets as to where it is going, and then the researchers can make sure that the work they are doing is well targeted and will ultimately pull through into economic value.

Lord Kakkar: With regard to creating the focus that clearly needs to be provided ahead of committing to a Faraday-type initiative for fuel cells, is there any activity at the moment in trying to develop that type of focus and develop the energy policy that will attend the rationale for this type of fuel cell investment, and, if so, who is leading it?

Professor David Greenwood: I think you heard in the previous session that there is activity in the UK around hydrogen policy. That is critical, because it will be the thing that answers the question about which energy vectors in the UK will focus on which sectors.

On the question about bringing hydrogen and fuel cells into transport applications, typically the Advanced Propulsion Centre has been the main convener of the technology road maps for that sector and is now sponsoring projects. In fact, some were announced even just this week—for instance, the development of hydrogen fuel cell buses with Wrightbus.

However, we do not have the equivalent of a Faraday Institution to pull the industrial and academic communities together on hydrogen. The Supergens have done a good job of bringing the academic communities together, but we need to see something a bit stronger for bringing the industrial and policy communities into the same place.

Lord Kakkar: How might that be achieved? How could it be led or stimulated?

Professor David Greenwood: The battery and automotive markets came together, because industry saw a clear need. The order of events was quite simple. We signed up to climate policies. The climate policies took us into CO₂ requirements. That put a requirement on to manufacturers to develop products that were compliant, which meant that they needed technologies and supply chains that would answer them. We had to follow that cascade to make sure that there was a win-win for every organisation down the chain.

I do not think we yet have the clarity of policy in place on the applications of fuel cells that means that the industry is there and ready to push the button on the big investments that it will take to bring product to market.

Professor Paul Dodds: Fundamentally, the Faraday came about because industry was willing to put in a lot of money. I absolutely agree that it is not there for fuel cell transport at the moment, which is an issue. Maybe the focus will be on heavy duty vehicles, which is where hydrogen fuel cells will fit in better, and maybe on aviation and shipping too. There are a number of opportunities there, but potentially they are longer term and a little lower TRL than battery vehicles at the moment.

Q66 **The Chair:** My next question is pretty simple. Are our current funding sources likely to meet the R&D goals set by the Government for batteries and fuel cells?

Professor David Greenwood: For batteries, my previous answers about longevity and quantum notwithstanding, the structures that we have are progressing very well towards delivering against the goals that we need. For fuel cells, there is no equivalent mechanism in place driving that level of progress at the moment.

Professor Paul Dodds: I agree with that. There is no drive on fuel cells. The Government have the target for new car sales, for example, but I am not sure that there is an equivalent target for heavy duty vehicles, where we might start to use fuel cells, even though most companies that produce such vehicles worldwide are currently looking at fuel cell options and trying to develop them.

Professor Philip Taylor: I agree with Professor Greenwood and Professor Dodds. On Professor Greenwood's earlier comment about using hydrogen for heating, the UK is now blending hydrogen into the gas grids to help to decarbonise them and use that for heating. If that ends up being the major use, the pull on fuel cells will not be so great because we will just be producing hydrogen through electrolysis or using new nuclear to produce hydrogen that is low carbon, and then using it and distributing it in our gas grids. So there would be a need for more R&D in electrolyzers rather than in fuel cells. They are similar technologies and some of the skills are transferable, but it is worth mentioning electrolyzers there.

Professor David Greenwood: To follow up on Professor Taylor's point, when we think about the uses of hydrogen, we must remember that none of these fuel sources comes for free and neither are they in infinite supply. If we use renewably generated hydrogen to produce heat, we do

so at something like 95% efficiency. In other words, 95% of the renewable energy that we generate finishes up as the heat that we want. If we use that same hydrogen to provide torque in an electric vehicle, because of all the conversion losses that happen in the process only about 20% of that energy ends up at the point of use, so 80% of the renewable energy that we generate is unfortunately wasted on the way to getting there. So we need to think carefully about which applications are best suited to which fuels.

Q67 The Chair: I would like to change tack slightly. In the last panel, we discussed apprenticeships and skills. I would like to hear your views about what might skills levels be required for, let us say, a gigafactory by 2030.

Professor David Greenwood: We are just about to complete a piece of work at the moment. Loosely speaking, to staff a gigafactory about 3,000 people and needed, and it is a mixture of skills from shop floor level through manufacturing and engineering into laboratory science and technology, and of course managerial skills are needed to operate that.

We have been working with the Faraday Institution to put together a national skills framework for that, taking into account the number of people we will need at each of those levels and the types of skilling that they need. We hope very shortly to release that framework, which includes how people would access the training they need at all different points along the way.

A critical point for us in the UK is that we do not have time to generate all those skills from scratch, waiting for school leavers to come through a system. We will have industries such as the car industry, where people with skills that are currently associated with internal combustion engines and their manufacture could be retrained or reskilled to create the industries that we need to make electric motors, batteries, fuel cells and their balance of plant. It is therefore important that we do not just look at this as a question of how we grow school leavers into the skills that we need, but that we also think about what the mechanisms will be to take people who are already in industry and retrain them into the new requirements.

Professor Paul Dodds: We have a range of activities here, from basic research to developing new products, running manufacturing plants and doing energy service. We need a range of people in each. It depends to some extent on exactly how much time and effort we want to put into each area. Do we want to be a country that will essentially import other people's technologies but manufacture them here, or are we trying to get the really high value-added activities such as research and development?

You need very different skills. In one set, you need a substantial PhD programme, which we certainly do not have for fuel cells. For another set, you are retraining fitters or engineers to a different level. There is a range of different types of skills that you need. I do not think we have a clear view on exactly what we need for exactly which activities we are trying grow.

Q68 Lord Krebs: I want to build on some of the answers you have already given to previous questions by focusing on the gaps that you perceive in the current R&D activities in the UK in relation to battery and fuel cell technologies. For example—you commented on this a bit before—do the R&D advances translate across applications? Do advances in electric vehicles have spillover benefits for grid storage? I note that, for example, the US Department of Energy in 2016 received a report suggesting that redox flow batteries and zinc-ion hybrid batteries might be used on grids rather than lithium-ion batteries, as in electric vehicles.

In particular, what factors are important in driving research for the development of grid-focused technologies? Perhaps you could consider gaps, particularly in relation to the grid.

Professor David Greenwood: At the moment, in terms of the research gaps, we have done a very good job on our chemistry, electrochemistry and materials in the battery space. There is more to be done on engineering and manufacturing engineering, because that is what will bridge the scientific breakthroughs into commercial exploitation within the UK. A bit more focus on those would certainly be beneficial.

I agree about the types of batteries and applications for them; I keep coming back to the fact that we need to know what the application is to do the correct research. At the moment, the grid-scale storage industry is buying automotive batteries, because that is what is there and is cheapest. That has been the first market to move and, frankly, it has been where the biggest commercial gains are to be had by the battery manufacturing companies.

There is a good argument that, with the right market and the right funding mechanisms behind it, different types of batteries, such as lithium-sulfur or redox flow batteries, could be a better answer for grid storage. However, at the moment the market dynamics and the investment have not been there to do that.

There is one other area of battery technology which the UK could be extremely good at and is an emerging requirement: very high power density batteries. These are not batteries that are used to store all the energy that you need for your electric car to drive it from A to B, where it acts a bit like a fuel tank. These batteries act as a buffer for energy—short-term demand. The aerospace industry needs that, the off-highway industry needs it, the rail industry needs it. It is an area where the UK has very good academic strength and a very good track record from work that we have done in motorsport and other applications.

Professor Philip Taylor: I agree with Professor Greenwood. As Professor Dodds said earlier, there are spillover benefits from the automotive battery developments to grid applications. There is a really interesting project called E4TheFuture, with Nissan and National Grid, looking at vehicle-to-grid technologies and using a growing fleet of electric vehicles to stabilise the grid and help it decarbonise.

Where the gaps start to appear is at really large-scale energy storage, which we will need in our grids as we decarbonise them. At the moment,

lithium-ion technology does not really look optimal for those kinds of applications. So there are some gaps in the funding landscape and in our activities in the UK, looking at those larger-scale, longer-term energy storage solutions. I emphasise the word “energy” there rather than “electrical” storage. We need to think about heat storage and translations between those to help us with our overall energy system.

Professor Paul Dodds: The largest number of fuel cells in operation worldwide support the grid. These are hundreds of thousands of micro-CHP fuel cells installed in homes in Japan, generating electricity and providing heat to those homes. That is the main market at the moment rather than vehicles, although in the longer term vehicles have long been considered the biggest potential market for hydrogen fuel cells.

On the question of what is missing for fuel cells, it is perhaps fuel cells that are powered using ammonia, particularly for aviation but potentially also for shipping, trains and heavy goods vehicles. That is because liquefied ammonia has twice the energy density of liquid hydrogen. It is fairly easy to transport and it liquefies at 10 bar or so. You could produce ammonia from renewables in countries such as Australia, Chile and Saudi Arabia very cheaply, probably more cheaply than the UK could produce hydrogen. The aviation sector is starting to take a greater look at ammonia as a fuel, particularly for shorter-range or medium-range flights of up to about 4,000 kilometres.

Lord Krebs: Let us suppose that ammonia was developed as a fuel for trains or short-haul flights. Can you convert the existing aeroplanes and trains to run on ammonia, or do you have to wait to build a new fleet? The lifespan of, let us say, the high-speed train in this country was 45 years, so even if you had a new technology to run trains on ammonia, would all those recently bought Hitachi dual-fuel trains have to be ditched and we would have to buy a new fleet?

Professor Paul Dodds: You would almost certainly need a new fleet of aircraft. I do not think the existing fleet would be able to use ammonia. Trains are an interesting question. The answer is that I am not sure. Electric trains generally have a motor under each carriage. I guess you could power those motors using a fuel cell in a carriage at the front, so it might be possible to convert it if it were possible to add an extra carriage.

Professor David Greenwood: I certainly agree that there is no way you would be able to carry an existing airframe on to this kind of technology. For the aviation industry, it would need a completely new design to do that. For the rail industry, rolling stock for the most part would remain constant and you would need to change the traction unit that goes into it, but we should not mislead ourselves as to the timescales involved. If we were talking about the development, commercialisation and ruggedisation of ammonia fuel cells, that would be comparable to the timescale of the life of some of these platforms. It is not something that we will have to do tomorrow. It is a decade away as a challenge.

Q69 **Baroness Blackwood of North Oxford:** Professor Greenwood and Professor Dodds were pretty clear about what they thought had been the

relevant factors in driving forward the research and development of batteries and why the same had not happened to such an extent with fuel cells.

I think I know the answer to this question, but do you think there is a need for greater co-ordination across all the TRL levels in battery and fuel cell research? Do you think it would lead to greater success in the route to net zero?

My second question is: do you think that we have any further gaps further upstream in making sure that we have identified sustainability in the supply chain?

Professor David Greenwood: On your question about the linkages between the TRL level, we have mentioned a few times that one of the things that really makes the Faraday stand out internationally as a successful mechanism is the connection between the TRL levels and the common governance between early-stage academic research right the way through to the folks in government supporting inward investment for people coming to the UK to put a gigafactory in place. If we were to make fuel cells operate at the same speed, that TRL linkage would definitely be worth while.

In answer to your question about the upstream gaps, it is very easy to get focused on the big investments in all this. In batteries we tend to focus on the gigafactories—huge one-kilometre-square £4 billion investments. We must not lose track of the fact that those gigafactories need skilled people, but they also need supply chains, and those supply chains are industrial chemicals companies, people in some cases doing plastic mouldings, steel pressings and things that already exist in this country but that will need to move across into a new industry sector to support it as it grows.

For the translation of conventional industry into new markets, I am not too worried. Those companies are actively looking to do that today and there are some mechanisms out there to support them. The piece that worries me a bit more is about making sure that we have the conversion supply chain, companies that can do things like electrolytes, cathode and anode materials, foils, separators—all the components that go into the battery.

A particular challenge there is timing. Tony Harper in the previous session probably talked about chickens and eggs along the supply chain. The challenge that we have at the moment is that the supply chains are quite linear and each actor in the supply chain is looking at the one ahead of them before they make their move. The battery manufacturing company is waiting for the car company to give it an order to buy the batteries, the supply chain company to the battery factory is waiting to see the battery factory there before it invests in something to make the materials for it, and its suppliers are waiting for a signal from it.

One thing that we could do well as a Government is to look at what we could do to de-risk those investment decisions all the way down the

supply chain so that they march in step rather than waiting for the next one to move before they make their own decision.

Baroness Blackwood of North Oxford: Professor Greenwood answered the question about the link of TRL co-ordination through the fuel cell chain but also perhaps between fuel cells and batteries.

Professor Dodds, on the supply chain question, one of the barriers to scaling, as I understand it, is the pure supply of raw materials. Is there something in the re-use of those materials and increasing the sustainability of that market within the UK?

Professor Paul Dodds: Professor Taylor mentioned electrolyzers earlier. Electrolyzers and fuel cells are very closely related and it certainly makes sense to co-ordinate their development.

In terms of the technologies, you will have a proton-electrolyte membrane electrolyser and a proton-electrolyte membrane fuel cell, for example. Reversible fuel cells work both ways. So that is important. There may be some potential for co-ordinating the batteries too, particularly if you are thinking about applications and systems engineering to build products that will use both batteries and fuel cells.

In terms of the supply chain and the barriers, the fuel cell business is really very international. Johnson Matthey, for example, is a FTSE 100 firm. It has a large fuel cell division that principally produces materials and membranes for fuel cell stacks, and it exports worldwide. More than half the companies we surveyed work with overseas companies or institutions. It is a really global business, and there are a lot of global links.

If we look upstream for sustainability and how the supply chain is actually working from the UK, part of it will not exist, but that is because it works in the global sphere and because there is no market in the UK. There are markets in other countries, so those companies need to export in order to survive.

In terms of raw materials, there has long been a focus on reducing platinum in fuel cells, because the supply is potentially limited and because it is high-cost. That has more or less happened. There is now far less platinum in fuel cells, and car manufacturers have gone from trying to reduce the cost of the fuel cell to just trying to reduce the cost of every part of the car. They do not worry as much about the cost of the fuel cell anymore, because they have come down to the level where it is not worthwhile relative to other components such as the fuel tank.

I imagine that work is still needed to understand all the raw materials that are required for fuel cells.

Baroness Blackwood of North Oxford: Thank you so much.

Professor Philip Taylor: There is definitely scope to improve the integration across TRL levels quite significantly. The catapult centres are important in that space. The energy systems catapult and the High Value Manufacturing Catapult have a big role to play and we can build on that, particularly in linking across with SMEs. It is easier working with large

companies, and it is quite challenging working with an ecosystem of small and medium-sized enterprises, and catapults can help an awful lot there.

The whole life-cycle analysis and circular economy aspects here are very important. We use recycling across fuel cells and batteries, and that needs more attention. We can also see real ethical problems with, for example, the supply of cobalt for battery technology at the moment, and we need to be cognisant of that.

Professor David Greenwood: There is certainly more that I can add on sustainability. There are three main things that we would want to do in order to improve sustainability. We would particularly want to reduce the embedded carbon emissions associated with battery manufacture.

The first thing, which might seem odd, is to invest in charging infrastructure in the UK. If we do that, we can make the batteries smaller and lighter in the vehicles that we have today, which means that making them consumes less energy. That can be done without changing any of the battery chemistry or any of its manufacture. It is about putting an infrastructure in place that means that we do not have to put a 600-kilogram battery in every car on the road.

The second thing is to engineer out the materials, such as cobalt, that cause ethical and embedded carbon challenges. There is a very active research community in the UK looking at technologies such as sodium ion, lithium iron phosphate and lithium sulfur that do not have those strategically important materials in them and which are much cheaper and more sustainable to deal with.

Thirdly, we need to put in place a very good recycling infrastructure that is able to make sure that the materials we are embedding in systems today remain in the system so that we do not have to re-mine every time we want to create a next generation of product.

The Chair: Thank you, all of you, for helping us with this inquiry today. It has been most informative. We need to stop, because we are about to have a minute's silence. Thank you very much, and goodbye.