



Select Committee on Science and Technology

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

Tuesday 27 April 2021

10 am

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Members present: Lord Patel (The Chair); Baroness Blackwood of North Oxford; Baroness Brown of Cambridge (co-opted); Viscount Hanworth; Lord Kakkar; Lord Krebs; Baroness Manningham-Buller; Lord Mitchell; Baroness Rock; Lord Sarfraz; Baroness Sheehan; Baroness Walmsley; Baroness Warwick of Undercliffe; Lord Winston.

Evidence Session No. 8

Virtual Proceeding

Questions 90 - 97

Witnesses

Jo Godden, Managing Director, Fuel Cells, Johnson Matthey; Dr Mark Selby, Chief Technology Officer, Ceres Power; Professor Marcus Newborough, Development Director, ITM Power.

USE OF THE TRANSCRIPT

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

Examination of witnesses

Jo Godden, Dr Mark Selby and Professor Marcus Newborough.

90. **The Chair:** Good morning, everyone, and in particular a very good morning to our three key witnesses: Ms Godden, Dr Selby and Professor Newborough. Thank you all for joining us today. We much appreciate you giving up your time to help us this morning with this inquiry. To both committee members and our distinguished witnesses, the time is always hard to keep to because it is so limited, but it would be helpful if you would please try to be quick in your questions, and short and succinct in your answers.

I will kick off with the first question. What are the different kinds of fuel cells and what are their applications? How could they be helpful in the process of decarbonisation, particularly of transport? Do fuel cells have to be manufactured for different applications separately or can one process of manufacture deal with all applications? I will start with Ms Godden.

Jo Godden: Good morning, everybody. I have had a 25-year career in the chemical industry, starting with ICI, and for the past 18 years I have worked for Johnson Matthey plc. My current role is managing director for the fuel cell business.

The primary type of fuel cell is a PEM—polymer-electrolyte membrane or proton-exchange membrane. This type of fuel cell will operate between 60 degrees and 100 degrees centigrade and will start up from sub-zero temperatures. This is a really good choice for decarbonising transportation and can also be used in other applications where hydrogen can be provided.

There is also a direct methanol fuel cell. That is a special type of PEM that is designed to be fuelled by methanol. The power density there is limited and it is less useful in decarbonising.

A third type of platinum-based fuel cell is a phosphoric acid fuel cell. That operates at higher temperatures of 180 degrees to 200 degrees centigrade. They are difficult to start up from cold; the environment has to be well controlled. These are more suitable for combined heat and power-type solutions.

I will let Mark comment on the solid oxide fuel cell. We should use renewable electricity wherever it makes sense, because it has the highest efficiency, but where there are hard-to-decarbonise applications, such as shipping, heavy transport, steel and chemical manufacture, clean hydrogen and its derivatives are a better solution. Fuel cells make sense for heavy goods vehicles due to the longer driving range, more rapid refuelling and the lower payload penalty.

Finally, on the methods of manufacture, they can be for any application. Stack and system developers tend to specialise in the application, but MEA manufacturers such as Johnson Matthey can tune their product for many applications and optimise the performance.

The Chair: Dr Selby, do you have anything to add to that?

Dr Mark Selby: That is a pretty good summary. The takeaway is that there are many fuel cells for many different applications. If you think about batteries, it is not that dissimilar. We do not use the same battery to start an engine as we would use to run a remote control or put in a mobile phone. There is an ecosystem of technologies. Jo has just talked about several that are aligned with pure hydrogen and particularly aimed at transport. Higher-temperature solid oxide fuel cells are a bit more general. Traditionally, they are focused at stationary power. They are very high efficiency and can work on any fuel, from hydrogen through to natural gas, or even diesel if you wanted them to.

When you think about decarbonisation and the next journey, hydrogen is going to be important. Some of the future fuels like ammonia and synthetic methanol from green hydrogen and renewable electricity start to be particularly relevant for those higher-temperature technologies.

The Chair: Professor Newborough, do you have any additional comments?

Professor Marcus Newborough: Good morning. I would add only that you should remember that a fuel cell is a one-step conversion from a fuel to electricity. It is relatively efficient compared with an engine technology and, unlike engines, does not create any pollution. It does not emit anything. Therefore, it is a very clean solution, and in the context of a vehicle it enables going directly to an electric powertrain, which gives you a very efficient vehicle. A fuel cell vehicle is substantially different from an engine vehicle, even if both were using hydrogen.

The Chair: Baroness Brown, do you have a comment or question?

Baroness Brown of Cambridge: I would be interested in hearing a bit more about the relative efficiencies of the low-temperature fuel cells and high-temperature fuel cells. People have said these are slightly more efficient or less efficient. What is the conversion efficiency as regards the energy you start with and the energy you get out?

Dr Mark Selby: If you start with the higher-temperature ones, on natural gas we have products running today at about a 65 percentage point efficiency. If you compare that with central generation, it is more like 50%, and then you have the transmission losses. The state of the art for those high-temperature technologies is well over 70%, but that is not a commercial product yet and we have projects in the US with ARPA-E working on these concepts.

If you come down to those lower-temperature ones, a fuel cell can be operated at any efficiency you choose. The question is how much you want to pay for your efficiency. Typically, lower-temperature fuel cells operate anywhere between 40 percentage points and 55 percentage points efficiency, depending on your commercial choices in engineering. It is very different from the intrinsic limitations that you get in a carnot cycle in a combustion engine.

Baroness Brown of Cambridge: It is really critical in comparing the

cost of hydrogen with the cost of fuels you might use, for example, in an internal combustion engine, because if you have something that is much more efficient than the internal combustion engine it means you can afford a more expensive fuel. If we can drive up fuel cell efficiency, it would be interesting to know what the limits are likely to be.

Dr Mark Selby: The limits at low temperature are probably 50% to 55% and at high temperature somewhere between 60% and 75%.

Baroness Brown of Cambridge: Does anybody else want to comment on that?

Professor Marcus Newborough: The key thing to remember is that a fuel cell vehicle uses only about 40% of the energy of a modern petrol vehicle; therefore, you have to carry less energy to travel the same range. That is a very big advantage.

Baroness Brown of Cambridge: But a modern diesel engine can be 40% efficient.

Dr Mark Selby: Baroness Brown, I think that is a bit of a myth sold by the car industry. Combustion engines work in a very narrow operating range. You can find a point on an engine map that has 40% efficiency, but when you look at the drive cycle that an engine goes through, you never get a cycle-average efficiency as high as 40%. It is a bit of a myth. It is grounded in good data but it is not the real world.

Professor Marcus Newborough: It is also worth saying that an engine vehicle must use a mechanical powertrain, which is much less efficient than an electric powertrain. What matters to the customer is how much energy they have to buy to travel the same distance. If you have to buy only 40% of the energy to run a hydrogen fuel cell vehicle, that is a substantial difference to running a modern diesel or petrol vehicle.

The Chair: That prompts another question, but I do not want to encroach on the other questions, so I might come back later. I will go to Baroness Blackwood.

91. **Baroness Blackwood of North Oxford:** One of the purposes of this inquiry is to make recommendations to government as to how to accelerate the development of batteries and fuel cells in order to achieve net zero. We are trying to understand what equipment, facilities and skillsets are needed to manufacture fuel cells, for example. Do you have any recommendations for that? Also, how well placed is the UK for manufacturing fuel cells? Do you have any recommendations for improving where we are at the moment? Perhaps, Jo Godden, you could start.

Jo Godden: With the right investments, the UK could really bolster its position in a significant part of the value chain here. In the fuel cell area, as with batteries, being able to manufacture at scale, at high volume, with high quality is key. The componentry—the catalysts, the catalyst-coated membranes and the membrane electrode assemblies—are already operating at scale with respect to the current global market size. It is very much now about developing and trialling new manufacturing

processes that will increase that order of magnitude by two or three over the next 10 years to get that total cost of ownership, scale and global reach.

As regards being well placed, in the supply chain we are already making many of the components, as I mentioned. The platinum into the PEM fuel cell comes from outside the UK, but there is already a well-established recycling network that brings platinum back from car exhausts, into the circularity and into production for fuel cell catalysts, so that critical and expensive raw materials can be sourced locally.¹

One area that is light in the UK, is in the stack and system development for the powertrain. A lot of that is overseas. The early developments have been with the car companies: Hyundai in Korea, Toyota in Japan, and General Motors in North America. There are fewer OEMs at the moment in the UK developing technology here. This is starting to gain some pace.

Really critical is having strong R&D and innovation in continuing our leading position in the UK. It is good to have the technology close to your manufacturing, but as you gain scale you can bring the manufacturing closer to the customer. It is more repeatable at volume to have that around the world in different regions, while continuing to innovate and develop the technology within the UK and have that support.

Baroness Blackwood of North Oxford: Dr Selby, following up on those questions and on the point that Jo Godden made, do you think that R&D and manufacturing need to be close together in the same place, or does it not really matter?

Dr Mark Selby: In some ways it depends on your business model. From a manufacturing point of view, we are not a manufacturing company or a product business; we are a licensing business. We have made investments in manufacturing in the UK, but that is to enable adoption. The majority of the manufacturing that will happen from our technology will be through licensee partners. Today, Bosch has taken a licence and is building a factory in Germany. Doosan has taken a licence and is building a factory in Korea. Weichai has taken a licence and is building a factory in China. We are doing the R&D for them because the UK is absolutely world-class in electrochemical technologies.

There are three questions: is the technology internationally relevant, can the UK play a commercial role, and can the UK play a manufacturing role? For the first two it is absolutely yes. For the last question as to whether the UK can play a manufacturing role, it is a "yes and". Yes, it can make them in the UK if there are relevant industrial parties committed to doing that, but it can also harvest value from international manufacturing. I am sure companies like JM would point to situations where they manufacture abroad and harvest revenue back to the UK. If you were to look at what Marcus does as well, between Ceres and ITM somewhere between 90% and 100% of the revenue to our companies is

¹ In the future with the right investments and support, we will see scaled up manufacture for fuel cell components, delivering a circular low carbon solution. This will increase the amount of critical and expensive raw materials that can be sourced locally.

from abroad. The commercial relevance of this technology to Asia and Europe is absolutely central. The UK is a real heavyweight in that respect.

Professor Marcus Newborough: We manufacture PEM electrolyzers in Sheffield in a gigafactory that we opened in January, which has taken several years to plan and develop. Our attitude is that we will open further gigafactories in the UK, or anywhere, where there is a substantial market or a Government willing to facilitate such growth. In my experience, it has always been best to keep the R&D people close to the manufacturing people if you can. You need to own and invent the IP; you then need to exploit it. That is about engineering and about making products that sell to customers. You need to modularise your products and understand the whole chain. If you can understand the whole chain, you are in the strongest position.

From an electrolyser point of view, we know we are in a world-leading position right now by having the first gigafactory. We can produce 1 gigawatt per annum of electrolysis. I think something like 90% of it is going overseas into overseas markets, but there is a large potential untapped home market for making green hydrogen because we have a very substantial offshore wind resource and other renewable resources in the UK.

From our perspective this is an end-to-end possibility, using renewable energy from the UK to make both renewable electricity and renewable hydrogen, and then deploying that hydrogen via our electrolysis equipment into the different sectors of transport, industry, heat and power. We very much want to play into that whole end-to-end solution.

The Chair: I move on to Baroness Brown, please.

92. **Baroness Brown of Cambridge:** I would like to explore whether we are doing enough research and innovation not in the fuel cell technologies themselves but in the manufacture and the scaling-up. We have heard from the Supergen people such as Nigel Brandon at Imperial College, and there is the CDT at the University of Birmingham, but they are very much focused on the core technology rather than the manufacturing technology. Do we need to see more support in that area, or are companies covering that for themselves? Let me start with you, Jo.

Jo Godden: The automotive transformation fund has total funds of £1 billion for capital investment and R&D projects. It is very focused on industrialisation of the electrified automotive supply chain to get to that scale. I think this is a really good start and a welcome targeted area to focus on scale-up. There is also the Advanced Propulsion Centre, with a number of products in the portfolio. The investments there in fuel cell scale-up is relatively modest at this point and there is some for hydrogen tanks.

Again, it is a starting point, but from Johnson Matthey's perspective the manufacturing processes are quite modular. It is very much the infrastructure enabling the market to happen that will be important—supporting the hydrogen refuelling infrastructure and enabling more and

more vehicles to run on hydrogen, as well as keeping on investing in future technology and bringing that through to scale.

Baroness Brown of Cambridge: Is there enough investment in the rest of the system components? You mentioned briefly, of course, the hydrogen tanks. Do we have research and innovation going on in the whole system to complement the fuel cells themselves?

Jo Godden: There is probably a lot more to do there. Mark can probably comment from a solid oxide perspective. The key raw materials—ionomers—tend to come from chemical companies overseas. Bipolar plates are a key element of the stack and the performance. It is about having those deeper capabilities in the UK.

Baroness Brown of Cambridge: Mark, may I come to you?

Dr Mark Selby: There are two parts to that question. I will start with the second part. There is a degree of selfishness in all countries about how they maximise their content in the supply chain. Therefore, wherever these technologies are important, whether it is Asia or Europe, there is a strong drive to localise as much of the supply chain as possible. The UK talks about that in the automotive industry also. That will happen. I would say that the UK supply chain today, for either system components or raw materials, is not strong. There are certainly opportunities to do more in that respect. If you look at our technology, by weight it is 97% steel. We source that from various places around the world. We do not get raw materials at the right quality, or with the right specific properties or industries in the UK, and I suspect JM is similar.

Are we doing enough investment in R&D? You limited your question to manufacturing, but I would say no across the board. If you look at EPSRC, in 2019 it spent £7 million in this space. If you look at Japan, it spent £200 million on the same topic. We are not investing at a necessarily competitive scale, although private finance in the UK—the City—is a very effective proxy for government interventions in that regard.

If you look at late-stage government interventions, Jo mentioned APC—the Advanced Propulsion Centre, based in the Midlands for the automotive industry. That is an excellent institution. It has a very narrow remit towards propulsion technologies. One thing that is becoming apparent globally, but the penny is also dropping in the UK, is that fuel cells, batteries and electrochemical technologies will work across the energy system. If you talk to the leadership of organisations like the Advanced Propulsion Centre, they would say this model works for late-stage innovation, manufacturing and scale-up but that it is probably too constrained in its automotive remit.

There are a couple of options for the Government. They can either broaden funds such as APC and Faraday to the electrochemical technologies, because that is really what we are talking about at the next level up in science and engineering, or seek to model institutions on the APC, which provides that late-stage funding, in areas where we want the UK to play internationally.

That is probably my biggest issue with a lot of the policy and, in some ways, the questions we are talking about today. There is a real focus on UK tech for UK problems, and we have to think about UK tech for global problems. That will necessarily mean that we seek to enable manufacturing globally embedding UK technology. The funding structures and the investment support are not necessarily aware enough of the commerciality and the business models required to commercialise UK technology internationally, through either manufacturing or intellectual property routes.

Baroness Brown of Cambridge: Thank you, Mark. Marcus, is there anything quick you want to add to that?

Professor Marcus Newborough: I would add that engineers have the appetite to improve and take cost out of products. There is a natural route before us now to semi-automate and then fully automate as the volume of the market increases. That pulls through the sort of improvement and cost reduction that we will see over this decade, and it is natural that it should do. The majority of our supply chain is in fact British because it makes sense, but when there are components that need to come in from overseas because they are so good or so cheap, that will dominate the decision. If the gap is too big, there is no way of filling it.

93. **Viscount Hanworth:** Which fuel cell technologies are closest to being realised at scale in the UK to meet the 2050 net zero target? Perhaps something more can be said about ammonia fuel cells, which have been proposed for shipping.

The Chair: Who would like to start?

Viscount Hanworth: That one is perhaps best for Mark Selby, who has already mentioned ammonia.

Dr Mark Selby: I guess Jo will comment on commercialisation. PEM and solid oxide are being commercialised internationally already. They are not being commercialised in the UK. The largest fuel cell sector by revenue is phosphoric acid. Doosan generated over \$1 billion-worth of product revenue off phosphoric acid technology out of its factory in South Korea last year. However, that is an older technology and it is replacing that technology with PEM and solid oxide fuels—fuel cell technology—partly because they access more markets and are much more efficient.

As an energy vector, ammonia is really a carrier of hydrogen. It is not a fuel in its own right. It is a way of taking renewable energy at relatively high efficiency, turning it into hydrogen and creating a very energy-dense vector in ammonia. There are three ways of using that ammonia. You can burn it in engines, but that is not a great thing to do. You can crack it back to hydrogen and run it through low-temperature technologies, but that is a relatively complex process, or in higher-temperature fuel cells such as the solid oxide cells you can use it directly at very high efficiencies. Typically, it would have over 60% efficiency in a largescale solid oxide fuel cell plant.

We certainly have a number of active projects in the shipping sector at the moment through our partner in South Korea, Doosan, but if you look to Europe one of the biggest actors at the moment is the Maersk Mc-Kinney Møller Center for Zero Carbon Shipping. It is a very active organisation which is currently pioneering solid oxide fuel cells with ammonia on ships. It is funded by Maersk and a range of other European actors in that space. That is a very active commercial development.

Viscount Hanworth: Presumably, the ammonia would be created by the Haber process, which is immensely consumptive of energy.

Dr Mark Selby: If you look at it, that is true and not true. Something like 94% of the energy that goes into the Haber-Bosch process is to release hydrogen from methane. The Haber-Bosch process itself is relatively low energy intensity. If you couple the Haber-Bosch process with green hydrogen, again, you can do that in two ways. You can do it from a low-temperature electrolyser, which Professor Newborough will talk to, or you could use a high-temperature solid oxide electrolyser and integrate those high-temperature processes. You can get to over 80% efficiency from taking renewable energy and converting it into ammonia.

When you look at the full round-trip efficiency of 80% efficiency from renewable energy to ammonia, and 60% efficiency back from ammonia to electricity, you probably have one of the highest round-trip efficiency energy systems anywhere in the world. If you think about that, that is really important. The leverage of efficiency on that round trip is enormous. One percentage point of efficiency on ship across a whole fleet is thousands of offshore wind turbines. As Baroness Brown pointed out earlier, efficiency is absolutely central to decarbonisation in some of those new energy systems.

Viscount Hanworth: This is all good news. Do I have time for another supplementary?

The Chair: I thought you were going to ask Ms Godden to speak about manufacturing at scale.

Viscount Hanworth: Indeed, I was intent on asking: what are the economies of scale that exist in the production of fuel cells, and are gigafactories a realistic prospect in the UK?

Jo Godden: The expansion and manufacturing at scale for the components—membranes, catalyst-coated membranes and membrane electrode assembly—is not a gigafactory. It is more of a modular approach to the technology there. We are pretty much at that scale now. It is all around improving the automation, improving the process and getting to a lower cost of production so that we can scale as the market scales.

For the stack, and very much the same for the electrolyser, as Marcus has commented around the ITM gigafactory, that is where it really makes sense in stack and system production and electrolyser production. It would be important for the UK to be well positioned there as well.

Viscount Hanworth: Would anybody else like to elucidate this issue?

Perhaps not.

94. **Lord Kakkar:** What will be required to increase the manufacture of fuel cells in the UK in the coming years in both establishing a definite market for them and the development of the hydrogen infrastructure required? Professor Newborough, perhaps you would start. If I heard you correctly, you made a point about understanding the whole chain in that pathway so that we have in policy, government action, and so on, a true understanding of those requirements in a joined-up fashion to deliver what we would hope to achieve by way of manufacture and adoption.

Professor Marcus Newborough: At the moment we have a large policy gap in the different sectors. We have an advanced position on renewable electricity, which is doing good work in a decarbonisation sense, but we use about 80% of our energy in molecular form as a fuel. We need the equivalent of renewable electricity as a fuel. Renewable hydrogen is that equivalent. As has been said, it can be used to make ammonia and other things as well.

The key point for the UK is that there is a huge amount in the long term that we could harness—I think Imperial College has estimated something like 1300 gigawatts of ultimate offshore wind potential, which is 25 times the peak power demand of the country—but you could not possibly put all of that into a power grid. You would need to convert it into hydrogen and possibly into methanol or ammonia, or other things.

This puts the UK in a very strong position because it has the resource, which France, Germany et cetera—our competing nations—do not have. That is the start point for it. If you could then manufacture the required electrolyzers and fuel cell technology in volume, you can bring their costs down and start to implement them in different ways, in different sectors.

We are an electrolyser manufacturer; therefore, I offer a couple of examples on that. One is clearly to enable hydrogen vehicles to be used across the UK as zero-emission, long-range, rapid-refuel vehicles. That needs a transport sector policy. Things like the RTFO, the bus service operators grant and the VAT level on hydrogen fuel are important to transport. We also have significant amounts of oil refining and ammonia production, and other processes that already use hydrogen, but that is grey hydrogen and we need some form of policy to persuade those processes to move across to green hydrogen. They would then decarbonise because of that.

Then you have the issue of the gas grid and how you distribute energy via it in the future. The hydrogen backbone in Europe is under development, for example. Electrolysers feeding hydrogen into the grid therefore need to be incentivised in some way to move us away from natural gas. I do not know how well I am answering your question but each of these little policy gaps need adjustment, and then you would start to see technology implementation.

Lord Kakkar: Jo Godden, do you think it is rational and plausible for us to have a national strategy that establishes a market and develops all of this infrastructure in a reasonable timeframe?

Jo Godden: I do think this is very important. If we look at what other countries are doing, the EU member states have set targets for their national hydrogen strategies. They have targets for numbers of hydrogen refuelling stations by 2030, fuel cell light-duty vehicles and heavy commercial vehicles. Around the world, China has really moved forward with a subsidy scheme, which is very much around investing in the domestic supply chain. The subsidies go to the automotive OEM when the performance targets of those components are met and a number of kilometres have been driven. That is enabling the investment in the supply chain in China, in the EU, and in other countries.

In the early days there will be relatively low number of vehicles that come onto the road, but you need to have the available refuelling infrastructure. It is very similar to battery electric vehicles where we are investing in the charging infrastructure so that the uptake by consumers becomes a realistic option. Supporting that while the numbers increase to get that infrastructure in place on the most-used routes, particularly for heavy goods vehicles, bus routes and hubs in cities, would be a targeted approach to put in place that infrastructure and get people familiar with seeing fuel cell vehicles in use and the efficiencies that come from that.

Lord Kakkar: Dr Selby, do you have anything to add?

Dr Mark Selby: Yes, there are a couple of things on that. When you talk about policy instruments, the question is: who has the biggest problem, and who is going to lose the most money in a carbon-constrained world? Those are the people you need to persuade that a carbon-constrained world is coming.

If we take as an example one of our partners, Bosch, it is heavily integrated with the automotive industry. It is one of the world's largest tier 1 suppliers for the automotive industry. It generates 60% of its revenue from technologies that support combustion engine deployment. It looks around the world today and knows that combustion engines are coming under pressure, and therefore 60% of its revenue is coming under pressure. Bosch alone invested €1.2 billion in the last 12 months in fuel cell and electrolyser technology.

If you put this into scale, for the companies in the UK that have the biggest problems we should seek to deploy policy instruments to motivate them, and to think about a carbon-constrained world. Marcus has already mentioned it. You can look at the refineries, the steel industry or the cement industry. Those are all industries that are ripe for reinvestment in the UK and for playing a huge role in decarbonisation, and ripe for getting us back on the international stage as a trading nation. Green steel should be a focus.

We talk a lot about hydrogen for automotive, as Jo has just done, because it is very familiar and very tangible. If you look at international commentary on hydrogen, there will be a willingness-to-pay issue. Hydrogen is probably the second-best solution for automotive and for heating homes, but it is the only solution for decarbonising steel. It is the only solution for decarbonising the agrichemical industry or the chemical industry. The willingness to pay in those industries, and the corporate

precipice that they are facing in that carbon-constrained world, is an opportunity for policy, and it is one that the UK is not taking.

95. **Lord Krebs:** I would like to turn the discussion to the topic of safety. Is the public perception of the safety of hydrogen a barrier to its adoption? If so, how could that be addressed? Perhaps in considering the answer you might also say what you think about the actual risks. What are the risks associated with the deployment of hydrogen fuel cells and hydrogen as a fuel? Jo Godden, would you like to kick off on that one?

Jo Godden: The safety of fuel cell electric vehicles or hydrogen vehicles should not be a big barrier. It is certainly all about education. They are designed very carefully to be safe. The hydrogen tanks within the vehicle will vent safely if there was an accident, and that removes the stored energy on the vehicle, which is difficult to do with other fuels. Of the vehicles that we have on the road in the UK, the Hyundai NEXO, for example, has a five-star Green NCAP rating. For public perception, the more used the public are to seeing hydrogen-fuelled buses on our roads, and using them regularly, as well as the battery electric vehicles and fuel cell powered commercial vehicles, trains and cars, the more it brings that confidence in the technology and that the inherent design is a safe design in this technology.

Lord Krebs: Have there been any hydrogen vehicle accidents of note? I know in the case of battery cars that there have been some fires; similarly, with smartphones, lithium ion batteries have burst into flames. Have there been any incidents with hydrogen?

Jo Godden: I am not aware of any and if there have been any, they have not reached the press in the way that lithium ion ones have. I am certainly not aware of any issues.

Lord Krebs: Marcus, would you like to add anything?

Professor Marcus Newborough: Yes, a general point and a specific point on transport. The general point is whether you are going to combust the hydrogen. If you make it electrochemically and then use it electrochemically, there are no ignition sources in that chain. For one of our hydrogen refuelling stations—where we produce hydrogen at the petrol station, compress it, store it and dispense it to a fuel cell vehicle—there is nothing in that chain that causes ignition or combustion. That is a discrete school of thought, if you will, and it stands quite differently from combustion processes, where the whole intention is to ignite and combust it. Clearly, it has very wide flammability limits and is a very leaky gas. It has a set of characteristics that means it has to be handled very carefully if you are to use it as a combustion fuel. That is the general point.

On the specifics of transport, back in the 1970s there was a very good example of this. It was perhaps NASA, I do not quite remember, which fired a rifle bullet at a hydrogen tank in the back of a car. You saw the jet exit the tank very quickly upwards towards the sky; the whole fire incident dissipated in a couple of seconds. They did the same thing for a petrol tank at the back of a normal car where you had what you can well imagine: a petrol flame, which spreads and ignites the whole vehicle, and

gradually burns away across several minutes. People can be shown things that improve their understanding of the difference between hydrogen and natural gas or hydrogen and petrol. Obviously, we have a lot of education to do there.

Lord Krebs: Mark Selby, did you have anything to add?

Dr Mark Selby: I would pick up on the general point. The key thing with any new technology is familiarity. When people understand the utility of something they are quick to adopt it. You can point to lots of things through history. In the 1980s I am sure my parents had one of those microwave detectors to see if they were going to get fried by a microwave. But as soon as the utility of that device becomes clear, people adopt it. The same will be true for hydrogen and a whole range of other technologies that we are not familiar with, and, therefore rightly, we ask careful questions about their safety. Proper engineering practice and familiarity deal with most consumer acceptance tests where there is real utility. I think history demonstrates that pretty well.

96. **Baroness Manningham-Buller:** I want to come back to the UK either having or seeking a lead. I know that some of our witnesses—Mark, for example—suggested that this is only part of the picture. The committee is interested in the policy changes that we will recommend, and Lord Mitchell will come on to that in a minute. Before we get to that set of questions, could any of the panel tell me where they think we really are in the lead and where we should aim to be a global leader where we are not yet—where we realistically and sensibly fit? Mark, you started on some of these answers earlier. Do you have anything to add?

Dr Mark Selby: The science base in electrochemistry in the UK is world class. It is slightly arbitrary to ask whether we are number one, two or three. The two or three centres of excellence in the world are spread across Japan, Germany and the UK. In terms of that early-stage science we absolutely are world class.

As regards the technology base being ready for commercialisation, we are also world class. Look at the money. Anyone who has chosen a high-temperature solid oxide technology in the last three to five years has selected Ceres technology, and that is happening all over the world. Again, I am not going to claim that we are number one in the world, but we have a commercial leadership position in technology.

The third leg of that chain is manufacturing, and probably the fourth leg of it is policy. In manufacturing and policy, for fuel cells and electrolyzers, we are a long way from world class. We have an opportunity, and it will be credible if there is the right policy and the right market position, but on those first two steps—the core science and the technology—we are absolutely world class in the UK.

Baroness Manningham-Buller: Professor Newborough, I understood you to say that there would be a really strong advantage, and you have built your own gigafactory, in having better manufacturing capacity at scale in the UK. I am not thinking of it just for the economics of the UK but to advance this issue of decarbonisation generally.

Professor Marcus Newborough: We are in a world-leading position as regards manufacturing PEM electrolyzers. Obviously, others can catch up and can overtake. We have a local, large renewable resource, as I described earlier, which means that we could make a lot of green hydrogen here, and, therefore, a lot of equipment will be required to make the green hydrogen here.

Obviously, in the business world you locate factories where it makes most sense. This depends on the policies of Governments in the nations you are considering and what the appetite is. If you look at certain Governments—Denmark, Portugal, Germany, Italy, France—they are all coming out very strongly for green hydrogen production from wind or solar power primarily, or hydro, and this gives confidence to not only the manufacturing sector but the R&D support for it, and indeed the investment community, that this is a growth area. Therefore, our perspective is that we will put these gigafactories down where it makes most sense. That is just the normal business logic of proceeding from here really.

Baroness Manningham-Buller: The policy framework for that is critical, and we will come on to that in a moment.

Professor Marcus Newborough: Absolutely.

Baroness Manningham-Buller: Jo, is there anything you want to add to what has been said already? I think Viscount Hanworth wants to come in.

Jo Godden: Just to reinforce Marcus's point that we have in the UK real global leadership in catalysis, electrochemistry and those technologies. It is about being able to build on that leadership position and having the funding and fundamental research and the academic and industrial partnerships: almost a Faraday-type scheme for fuel cells would be really fantastic to become a world leader in technology, as well as in the ability to manufacture competitively at scale.

Baroness Manningham-Buller: One of the questions this committee is interested in is whether we should have an equivalent Faraday for this area, so it is interesting you think that would be of value.

Dr Mark Selby: May I make one short follow-up point? It is interesting to listen to this conversation. We are talking about three quite distinct products: core technology, which we do and JM do; systems for green hydrogen production, which ITM does through Professor Newborough; and green hydrogen as a molecule or chemical product and how that creates value in decarbonising our society. We should not necessarily forget that we are talking about three distinct opportunities for extracting global value back to the UK. They are all strongly aligned, and the UK has a real pedigree in the infrastructure and crosscutting nature of science, technology and engineering. It is about not one market access point but technology, core materials and products. With all the resources we have, which Professor Newborough has talked about a number of times, it could also be green hydrogen. They are not necessarily entirely coupled but they are also not mutually exclusive opportunities.

Baroness Manningham-Buller: Thank you; that is extremely helpful.

The Chair: Baroness Manningham-Buller, were you coming back?

Baroness Manningham-Buller: No. I do not know if there is time to let Viscount Hanworth in—I see his hand is up. I had finished, thank you.

The Chair: Viscount Hanworth, do you have a quick question?

Viscount Hanworth: This is a somewhat delayed response to something that Marcus Newborough said. He talked of the production of hydrogen at fuel stations. I would like that to be compared with the efficiency of producing hydrogen by high-temperature electrolysis, which I had imagined would be the optimal way to do that.

Professor Marcus Newborough: My comment would be: what are you making the hydrogen from? If it is from electricity, at the moment we can make hydrogen at about 70% efficiency. We are converting electricity from the grid into hydrogen for a fuel cell vehicle, which then consumes about 40% to 50% of the energy requirement that a petrol vehicle would otherwise use. To me, that is quite an efficient chain. If we want to make hydrogen because we are adjacent to a high-temperature process, and are going to use the waste heat from that process for that hydrogen production, we can get a more efficient production of hydrogen. Where petrol stations exist or where we put hydrogen refuelling stations down generally, they are not adjacent to a waste-heat source of that temperature. Therefore, we need solutions that are generally applicable so you get a geographical spread across the country of refuelling facilities for cars, vans, buses, trucks, et cetera.

Viscount Hanworth: That is a very interesting scenario that I had not imagined.

97. **Lord Mitchell:** I have found this an incredible session. Thank you very much to the three of you for the input you have made. I have certainly learned a lot. I feel that the UK is in a very good position in many areas. The concern always is that we do not lose the lead, as we tend to in many areas. It is important that we go forward and really commercialise this to become powers in the world in this particular area.

With that in mind, and thinking about the Government's role, I would like to ask: what regulation do we need, what funding and what policy changes, to make us competitive and to meet the Government's targets? Perhaps, Professor Newborough, you can kick off.

Professor Marcus Newborough: For electrolysis and hydrogen production the interface with the electricity market is the critical one. It is the levies, fees and tariffs that electrolyzers have to pay to connect and use grid electricity to convert it into green hydrogen. That is the general area, and we need to recognise that our power grid is under-utilised. It could be utilised to a greater extent if we also used it to generate green hydrogen.

Specifically on transport, as I have mentioned, there is the RTFO—renewable transport fuel obligation—the production of green hydrogen

and the bus service operators grant. We currently subsidise the use of diesel with the latter, which creates a lot of pollution and is not the right thing to do. We currently have a VAT level of 20% on the sale of hydrogen fuel, which exacerbates the sale price to the customer. A bunch of things around those existing policies could be adjusted. There is also a need to target the number of refuelling stations one might require by 2025 or 2030, at depots for buses and trucks, and at petrol stations.

For the gas grid there is a need for a policy such as a feed-in tariff to enable the injection of hydrogen into the gas grid. For the large processes that we mentioned earlier, which currently use grey hydrogen, transitioning them to green hydrogen needs some form of stick and carrot to effect that change. There is a whole suite of actions that could and should be taken. As I said earlier, there is potential for us to make very large amounts of green hydrogen in the future if we get our home market policy correct.

Lord Mitchell: Thank you very much. Dr Selby, I am sure you have a lot to say on the subject and perhaps you could comment on it.

Dr Mark Selby: I would agree with all that. The one I would particularly amplify is the decarbonisation of those hard-to-abate sectors. Policy that encourages industries—cement, steel, ammonia—to think about green options from green hydrogen is definitely one of the biggest commercialisation opportunities in the UK. It probably also preserves the future value of those industries.

The second big one I would suggest, and we have already talked about it, is having a Faraday or an APC for this sector. They are quite different, but joined-up innovation support from low TRL, which is what Faraday does, through to relatively high TRL, which is what APC does, is also extremely valuable.

The third thing is to recognise the distinctions. As I mentioned before, there are different products here. It is about recognising that there are different products and that these need different commercialisation strategies. If you want to sell systems, you need to think about exports. If you want to sell technology, you need to think about intellectual property. You need to become conversant in valuing that in the UK. If you have conversations with the Civil Service in the UK, if you are an IP business, typically, you have a lot of education to do because it does not recognise the difference between a highvalue PhD job generating revenue at 60% gross margin compared to a manufacturing job creating revenue at much lower margins. Educating our thinking on our international position as regards a much broader set of commercialisation routes is the third thing I would strongly encourage.

Lord Mitchell: Finally, Jo Godden, we will be making recommendations on this. If you could have the final word in this session, what do you think the Government should do?

Jo Godden: A key message is making sure that the UK develops a joined-up hydrogen strategy across all these areas. Incentivising and funding the hydrogen refuelling infrastructure to overcome that short-

term gap in utilisation would secure the rollout of these stations and therefore attract vehicle placement in the market. OEMs in Germany and Asia that are manufacturing hydrogen fuel cell trucks, passenger cars and commercial vehicles will place those vehicles in a market that is moving forward in enabling the infrastructure and supporting that. That is a key area. Starting with buses and heavy goods vehicles, you will start to increase that visibility and consumer take-up and make this a great opportunity for us.

Lord Mitchell: A joined-up hydrogen strategy—I think that is a great idea. Would anybody else like to come in?

The Chair: May I ask a question? You have talked about hydrogen mostly and where it could be used in buses and trucks, et cetera, but do we have manufacturing in this country to use that hydrogen? Which industries in our country will use the green or grey hydrogen that we would produce?

Dr Mark Selby: Steel and cement, and all the refineries that make plastics from air-captured carbon; you have Wrightbus in Northern Ireland and Jaguar with a major programme on fuel cell vehicles. The list goes on and on.

The Chair: Lord Mitchell referred to recommendations. If each of you were to convert the evidence you have given today into one recommendation, what would it be?

Dr Mark Selby: A joined-up policy across the space, as Jo said. You have to start with that.

The Chair: Expand on that. In which areas is there a lack of joined-up policy?

Dr Mark Selby: Transport and heat. BEIS has only one target—to decarbonise heat, for example—but it does not really have any technology solutions to do it. It is competing with transport for the use of hydrogen. There are lots of inconsistencies across the Civil Service when you look at it.

The Chair: Does anyone else want to come in and give a recommendation?

Professor Marcus Newborough: For electrolyzers, the most important thing is to get the interface with the electricity industry working so that green hydrogen production is seen to be part of the mission of the electricity industry, and, therefore, the waiving of grid fees and levies to enable green hydrogen to be produced as economically as possible, and to motivate the continued expansion of renewable power. If you study what is happening in the electricity market, renewable power is suppressing wholesale prices for many hours a year now. Therefore, having a new load or new market for it firms that market, and enables and encourages the further expansion of renewables.

Jo Godden: I very much support the comments that have been made. It is about looking at how we can increase adoption. Hydrogen fuel cells are more nascent at this point in time than lithium-ion battery technology. It

is really building on this great opportunity for the UK. We are currently leading the way in a number of areas. It is about investing in the supply chain so that we can make a significant contribution to the UK and globally.

The Chair: There is one more minute if any other committee member has a burning question they wish to ask.

Baroness Brown of Cambridge: Could I quickly ask somebody to tell me something about the energy efficiency of fuel cells as a function of load and the rate of power delivery, and the efficiency of largescale fuel cell installations versus small ones as you might have for refuelling a car at a fuel station?

Dr Mark Selby: I guess the short answer is that bigger systems are usually marginally more efficient than smaller systems. On loads, fuel cells are relatively flat compared to combustion technologies. If anything, they go up slightly with reduced load. Peak efficiency is normally about 60% of rated design, but you will get very close to that across 60% to 70% of the operating range.

The Chair: When it comes to heat, as you mentioned, what is stopping it, for instance, compared to Korea? Should we have a demonstration of it? Is it a lack of infrastructure? Is it cost?

Jo Godden: Doosan is a real leader in Korea, and I think the Government have also incentivised the use of getting fuel cell stationary power and combined heat and power into buildings—hospitals, industrial buildings, commercial buildings. Is their target something like 80%, Mark, of their power needs for buildings?

Dr Mark Selby: I cannot remember but I know the number in energy. They have targeted 15 gigawatts by 2027. To put that in context, that is pretty large.²

The Chair: Thank you very much. I am afraid we have run out of time. Thank you to all three of you. You have helped us enormously. It has been a most interesting session and, as Lord Mitchell said, we have learned a lot. You have given us a lot of information to think about when we come to write our report. We appreciate it very much. You will get a transcript. If you have anything to add to it please write to us, and we will allow you to correct it if need be. Thank you for today and goodbye.

² This is five times the size of Hinkley C nuclear power plant, and brought on line in half the time.