HOUSE OF LORDS

Select Committee on Science and Technology

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

Tuesday 27 April 2021

11 am

Watch the meeting

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. 9 Virtual Proceeding Questions 98 - 104

Witnesses

Ian Constance, CEO, Advanced Propulsion Centre; Helen Simpson, Innovation and Projects Director, Porterbrook; Paul Stein, Chief Technology Officer, Rolls-Royce plc.

USE OF THE TRANSCRIPT

Examination of witnesses

Ian Constance, Helen Simpson and Paul Stein.

Q98 **The Chair:** Good morning to our three witnesses: Ian Constance, Helen Simpson and Paul Stein. Thank you all for joining us in this evidence session. We appreciate very much you giving up your time. Our time is limited, so I have asked committee members to be pretty sharp in their questions and I hope you will be pretty sharp and targeted in your answers.

Before we start, Paul Stein, I know aviation is a bit different because it is a different side of transportation and you cannot use batteries, or you may have different kinds of fuel cells. I am going to allow you to do an introduction first about your area.

Paul Stein: Thank you very much, Lord Patel. I am very honoured to be able to address the committee.

The Chair: For the record, please say who you are.

Paul Stein: I am the chief technology officer at Rolls-Royce plc. I would like to provide a wider context with a short three-minute opening statement on aviation decarbonisation and the contribution of batteries and fuel cells.

Seventy-five per cent of net CO_2 from global aviation comes from larger aircraft flying distances over 1,500 kilometres. Our route to net zero for these aircraft by 2050 is the ramp-up of sustainable aviation fuels. These are fuels made from non-fossil carbon derived from either bio sources or e-fuels entirely synthesised with zero-carbon energy, including from our own small modular reactor. Only 4.3% of global CO_2 comes from flights of less than 500 kilometres.

Liquid hydrogen is being proposed as a fuel for shorter ranges on medium to large aircraft, but we face many technical, safety and scaling challenges for this technology to play a significant part in getting to net zero by 2050. The industry is currently exploring this technology and studies are under way, but in any event hydrogen is most unlikely to power aircraft across the Atlantic where we will need these SAFs—sustainable aviation fuels—probably for the next 50-plus years.

We are about to discuss batteries and hydrogen fuel cells, which will play a small part in global aviation decarbonisation by 2050, but a very large part in creating a new generation of quiet, fixed-wing vertical take-off and landing aircraft. It is an exciting time for UK industry, which is set to open up a new era in mobility for people, cargo and military small aircraft applications.

The use of batteries, hydrogen fuel cells or turbo generators powering electrically-driven propellers or fans is seen as the third generation of aviation. New aircraft can be designed as quiet city hoppers, enabling human mobility like never before; electric vertical take-off and landing opening a new era, for example, in air ambulances being able to land in

crowded cities; or unmanned applications like crop spraying and cargo delivery. It is a pioneering time for aviation that the ATI is positioned to drive the UK ahead in.

Batteries and gaseous hydrogen fuel cells will displace less than 10% of global CO_2 but a much larger fraction of in-country aviation. Other attributes make this technology really exciting. I hope that helps the committee in providing a context for answering further questions. Thank you for the time, Lord Patel.

The Chair: Thank you very much; it helps. Of course, if the others have anything to say as an introduction, I will give them a chance to do so, otherwise I will get on to the questions. Ian Constance, do you have anything to say by way of opening remarks?

Ian Constance: No, but I will just introduce myself. I am from the Advanced Propulsion Centre and have been there about five years. Before that I had 25 years in the international automotive industry, working for Ford around the world. The APC is the agency responsible for innovation in automotive and low-carbon technologies.

The Chair: Thank you very much. Helen Simpson?

Helen Simpson: I am innovation and projects director at a company called Porterbrook, which owns over a quarter of the UK passenger fleet of trains. My role involves looking at new technology such as fuel cells and batteries. I am an engineer by training so hopefully can tell you a little bit about the technology in rail today.

The Chair: Thank you very much. Baroness Rock, would you like to start?

Q99 **Baroness Rock:** Welcome to all our witnesses. We are looking in this session at application in the transport sector. What role can batteries and fuel cells play in decarbonising road, rail and aviation? We heard from Mr Stein on aviation just now. In your answers, perhaps you could focus on some of the technical challenges—in the last session we heard some of the wider challenges—that need to be overcome with batteries and fuel cells. Ms Simpson, perhaps I could start with you.

Helen Simpson: The simplest way to decarbonise rail is to electrify the railway. We already have a large proportion of the network electrified. It is ideally suited for high-speed high-density passenger routes, particularly for freight where we have heavy haul freight moving around the country.

The *Traction Decarbonisation Network Strategy* sets out the plan for the next 20 to 30 years of how we are going to achieve that. But in that plan, we do not electrify everywhere and there will still be some less densely used routes that are not well suited or will take time to electrify. Some of the constraints around that are the loading gauge and the infrastructure—how high the bridges or tunnels are—and it is a question of whether you can electrify those routes, and whether it is cost effective to do so. We will have a problem there if we do not look at alternative traction types.

I have been looking at the use of hydrogen and battery trains and having a blended mix of those. Hydrogen trains will contain battery technology. while battery trains use the same kind of batteries as on a hydrogen train, so we are talking about the same technology for both.

There are challenges with fitting the equipment in. Clearly, there is a space constraint on our trains in the UK. We have a relatively small loading gauge, which is the size of tunnels and things that the trains have to fit through, so we have some space constraints to manage. Trains are also relatively high power: we have to produce quite a lot of power and have the right kind of it on board. Hydrogen fuel is obviously a very light gas and you have to pressurise it to store it, so there is a volume and space constraint. Batteries are heavier but more energy dense, so you have to allow for the weight and the mass distribution on the train.

There are some technical challenges, but there are new-build trains in Europe now with both battery and hydrogen technology. The major manufacturers are looking at those for the UK, to fit them and package them into our UK trains. We are looking at retrofitting this technology. I have been involved in a couple of projects looking at retrofitting a hydrogen train. Last year, we ran a hydrogen train on the mainline network to fit that technology to an existing train. Those are some of the challenges.

Baroness Rock: Mr Constance, could I come to you?

Ian Constance: My area of expertise is clearly around the automotive and road sector. It will be no surprise to anybody here that any car or light vehicle under 3.5 tonnes, such as a medium-size delivery van, is very much on a strong trajectory towards battery electric vehicles. Of course, that has been bolstered by the recent 10-point green recovery announcement from the Government, which will bring the sale of internal combustion engines to an end by 2035.

The speed with which that is going is very fast already, I would say. Clearly, regulations are driving that uptake. Probably what is stopping it is the supply of vehicles. Vehicle design, development and production is a huge investment for companies. Generally, they look to turn over their platform designs, the basis on which they build their vehicles, every 10 to 12 years. As those platforms come up for renewal, they will go more and more towards electric. Of course, plans put in place for the introduction of a new platform typically will take three or four years to develop, which means that whole cycle can take up to 14 years to clear through.

Those regulations are in place, so supply is on its way. As well as those vehicle platforms that dictate what kind of vehicles we drive, or what kind of vehicles the companies sell, there is a huge need to put this large-scale supply chain in place. I know you have had a number of discussions about the supply chain on batteries already. Batteries will be a massive part of that and a huge investment. There is a race around the world now to put that battery supply chain in place and secure it. The UK is in that race, and it needs to be to support its industry going forward.

Infrastructure is clearly going to be a big part of that. That means the ubiquitous supply of energy and charging points so that people can plug in more. Fundamentally, that supply question comes back to cost. Cost and consumer acceptance of these technologies are going to be really important. We will need a lot more ongoing innovation to bring those costs down to something that will be broadly acceptable and accessible for everybody.

If cars and light vehicles are on that trajectory, I think it is worth talking about fuel cells for a second. There is a role for fuel cells. Even in that 3.5 tonne and below segment, there are certain applications and users that need to travel long distances or haul relatively heavy loads, even at that level. At the APC, we see the opportunity for a degree of fuel cell penetration into that sector. We expect that to grow to perhaps 5% or 10%, starting in 2025 and up to 2035. I think 10% would probably be on the high side.

Again, demand at the moment is an issue for fuel cells because you can use a diesel alternative. It is much cheaper and easier to do that today. Of course, infrastructure and the availability of hydrogen—you have just been talking about that—is another major issue.

If that is the light duty element for road transport, the real area that is open and less clear is the heavy duty sector—long-distance haulage and perhaps buses and trucks as well. I would say that, if the light duty element is a two-horse race with battery electric winning but fuel cell still in the mix, heavy duty is probably a three-horse race with hydrogen fuel cells, battery electric with the potential perhaps for on-road charging, and then zero-carbon fuels of the type that Paul Stein just mentioned for aviation.

Clearly, the availability and cost of synthetic fuels will be very important. Availability may lead to policy positions to put that into aviation and marine applications.

Baroness Rock: Thank you. Chair, shall I hand back to you?

The Chair: Could I ask that your answers might be slightly briefer to match the time available?

Q100 **Lord Sarfraz:** Building on Mr Constance's last point on the challenges facing widespread deployment, specifically of passenger electric vehicles across the country, you mentioned varied performance and charging infrastructure. What needs to be done now for charging infrastructure to catch up? Mr Constance, would you like to have a go at that?

Ian Constance: I think there are two things. The home charging regime is well under way. People who buy battery electric vehicles can put their home chargers in. The bits that really need to be ramped up are the smart charging aspect and the aspect of public charging availability. To give people the confidence that they can go out and use their cars, we will need to see a lot more chargers available on the strategic road network and in towns and cities.

Lord Sarfraz: The Government announced £1.3 billion in the 10-point

plan to accelerate the rollout of the charging infrastructure. Is that enough?

Ian Constance: It is a tough one to answer. It is a good start, and clearly we need to spend that money and demonstrate that we can get there. There will be the need for a huge amount of chargers in rural locations, in city locations and on the strategic road network, and it will cost a lot of money. One of the big issues is the fact that land costs in the UK are very high, and providing the land to put these chargers in will be very expensive.

Lord Sarfraz: Would anyone else like to come in on that? Mr Stein, when will we have electric Rolls-Royce Phantoms on our roads?

Paul Stein: We do not make cars, unfortunately—that is the BMW Group—but I can answer it for battery flight if that is okay. Right now we are developing battery technology for very small fixed-wing aircraft. We can fly about 10 people about 200 kilometres with today's technology. That will extend up to about 350 kilometres by the end of the decade as battery technology develops, and we are targeting 500 kilometres by 2040. These are small aeroplanes that carry about 10 people, but it is very exciting. We have launch customers, particularly in the Nordic countries: for example, Norway wants to connect its population better by having an island hopper type of aircraft. That is how that market is developing quite quickly and in quite an exciting way.

The Chair: In the past it used to be only the rich who could fly, until it became cheaper. It sounds as if using battery and other technology will accommodate only a small number of people, and again it will be the rich who fly.

Paul Stein: The dream of many of the operators is the opposite. It is to help level populations, particularly emerging economies, so that towns do not have to grow up and down roads and rail, with apologies to Helen and Ian and their industries. Some of this technology is seen as quite low cost. The cost of running a pure battery aircraft, or even a hybrid electric aircraft, can be tens of percentage points lower than existing aircraft. It can be quite a levelling enabler for populations by providing a kind of bus service, for example, in Indonesia, which is a very islanded country, as you know. It enables the elements of that country to connect together in a way it cannot do today.

Baroness Sheehan: I agree with other committee members who have said how useful these sessions, including this one, have been. In light of the recent announcement that the *Sixth Carbon Budget* will include international aviation and shipping, what policy and regulatory issues need to be addressed for decarbonising these sectors? In your response, as well as the domestic scene, could you address what needs to happen on the international front?

Ian Constance: On the aviation side of it, I do not have a great deal to add. I think that is more Paul's area of expertise.

Baroness Sheehan: Paul Stein, would you like to respond?

Paul Stein: Thank you for the question. As you say, for these international transcontinental flights there is no doubt that it is international agreement with the big convening bodies such as the UN ICAO—the International Civil Aviation Organization—which will move the world in lock-step, for example, towards increasing blend mandates for these sustainable fuels. One plan being explored in Europe through the ReFuelEU programme is to go on a step-by-step journey demanding a particular percentage blend of sustainable fuels year on year. I think the UK can and is taking a leading role in driving that. That is very important.

The growth of sustainable fuels as a new industry is also extremely important. It is a massive undertaking. Trillions of dollars of capital need to be repurposed to get the volumes of SAFs that we need. The UK again needs to play its own part and work in lockstep internationally to make that happen.

For the so-called third generation of aviation—the shorter-range electric, hybrid electric and hydrogen fuel cell aircraft—the UK needs to promote the growth of a whole new industry. That involves getting the right certification and safety standards in place, in addition to all the infrastructure and air traffic management. For example, rethinking state subsidy control post Brexit is a good enabler for us in kick-starting industries that have been challenged in doing so while working within the EU state aid regulations. Those are the measures that I would take.

Baroness Sheehan: Do any of the other panel members want to add to that?

I want to ask one question. The Government have now agreed that they are going to accept the Committee on Climate Change's recommendation in its *Sixth Carbon Budget*. When the details of the Government's sixth carbon budget are released later this year, presumably before COP 26, what would you like to see in that for the aviation sector? We do not have any representation from shipping, but if any of you have any knowledge of the shipping sector and can comment on it that would also be useful.

Paul Stein: In aviation, to go back to the data, we have said that the vast bulk of global CO_2 is through these long-range international flights. We would hope to see the UK play a leading role technologically and in setting the policy agenda for decarbonising aviation through ever-more efficient engines—we need that because synthetic fuels, as Ian said, will be more expensive—together with working lock-step on a blend mandate. We would hope to see the UK take charge of these things.

My understanding of the marine sector is that international bodies such as the International Maritime Organization, which happens to be based in London, need to do something similar. It needs to move international standards on decarbonising shipping at the same pace.

Baroness Sheehan: Lord Chair, do I have time for another quick question?

The Chair: Very quick.

Baroness Sheehan: It is about the lifespan of aircraft. There has been a

recommendation in a Commons Library briefing paper of February 2021 that regulatory or policy measures to encourage faster replacement of older aircraft could be considered, as they have a very long lifespan once they are in use and from conception to use.

Paul Stein: That will happen through natural economics rather than any need for regulation. Sustainable aviation fuel, as the famous Royal Society report said in, I believe, 2019, has the same impact on the environment as, for example, hydrogen. It is net zero. It is a fuel where you take carbon from the atmosphere and return it. If you are burning more of it, it costs you more but it is not harming the environment any more. These fuels are going to be a little more expensive, so there will be some natural churn in the fleet anyway as operators running less efficient aircraft will just want to swap them out. Around 40% of the operating costs of an average airline pre-Covid are fuel costs. There will be, if you like, an automatic churn taking place in these old aircraft anyway.

Q101 **Baroness Walmsley:** I would like to return now to railways, so I shall be addressing Helen Simpson on this. Helen, you have told us that batteries and fuel cells are already being deployed on a small scale on the railway and that they are particularly appropriate for places where electrification is difficult or impossible. What are the technological, manufacturing and infrastructure challenges for deploying those batteries and fuel cells more widely?

Helen Simpson: We are at very early stages as regards the UK's approach to battery and hydrogen technology on trains, but there are significant steps forward with the manufacturers of trains in a worldwide sense. There are now some fleets being ordered in Europe and other places which will have have both hydrogen and battery trains. These are being deployed. We spoke earlier about the fact that we will need a very specific design for UK trains because of their smaller size compared to European trains. There are some technical challenges about fitting all the equipment inside or underneath the train.

We have a very strong safety culture in rail in the UK, with the safest railway in Europe, and we are world leading in our approach to safety on rail. We need to continue to manage that process. That is done through a very rigorous approach around risk assessment and regulatory standards compliance. The two things sit in parallel. We currently do not have standards for hydrogen trains in the UK, but we are working with the Rail Safety and Standards Board to develop those; they will be coming over the next few years. The regulatory safety approvals approach is developing. It is at a very early stage, but that will come.

Technology-wise, it is about fitting the equipment in, making sure that we have a safe and compliant train, and that it is a bit invisible to the passengers. As I always say with these projects, we want it to look like a normal train and not to be anything special, so that, whether you are using a hydrogen or battery train, you would not really notice any difference. The challenge is to improve perception of the risk as well, rather than just managing the safety.

Baroness Walmsley: Thinking back to the previous question, aircraft have a very long service life and so do trains. What are the challenges for retrofitting some of these technologies into existing trains?

Helen Simpson: Trains typically have a design life of 30 to 35 years in the way they are manufactured and financed in an economic way. Retrofitting has become more of an interest in light of the decarbonisation strategy. We might even be able to deploy battery or hydrogen technology on electric vehicles so that we create what is called a bi-mode train. That allows you to use the electrification when it is available and use the hydrogen or battery technology if it is not. In the interim, we are also exploring hybrid technology. We are working with Rolls-Royce on a hybrid power pack to use both diesel and battery technology and have reduced emissions. It is a kind of retrofit project to reduce emissions on an existing diesel fleet.

Baroness Walmsley: Are the batteries and fuel cells that are likely to be used in trains manufactured in the UK?

Helen Simpson: Parts of them are manufactured in the UK at the moment. I think Ian mentioned earlier a developing supply chain for that. The power packs needed for rail, typically, we buy in at 200 kilowatt sizes. We are at the bigger end of fuel cell manufacture and battery manufacture, so there is work to be done. Typically, battery cells are bought internationally and assembled into power packs suitable for trains. There are suppliers in the UK that are just beginning to get to that stage of development.

Baroness Walmsley: Do you think that the potential for this technology in railways is going to be sufficiently large to attract more of those manufacturers in the UK?

Helen Simpson: The battery technology itself is a modular design. The cells are exactly the same as would be used in other sectors. The battery cell technology is common. The way in which we package it and put it in a particularly secure box—that arrangement is bespoke to rail. It is the packaging of the technology that requires the bespoke rail knowledge, but the actual manufactured subcomponents are the same as used in other sectors.

Baroness Walmsley: Chair, I have finished, but I see two others have their hands up.

The Chair: I can see that, thank you. Lord Krebs, a quick targeted question.

Lord Krebs: A very quick question for Helen. When new rail infrastructure is being built in this country—there are plans to build new lines—given the long lifespan of rolling stock, should those new rail lines only be built if they incorporate low-carbon methods such as the ones you have described?

Helen Simpson: For new rail lines we are looking at two kinds of project in the UK at the moment. There are the new lines that are going to be electrified. As I said earlier, electrification is the simplest way to

decarbonise rail. That is a straightforward way to create a low-carbon railway. The other kind of line involves the potential reopening of older freight loops or other lines that have been closed for many years. There it is about building the business case for passenger growth and numbers. You only do that over time, and it will take a little bit of time to get to that stage. That will be a really good application for battery and hydrogen technology. Typically, the difference between the two is that batteries at the moment go somewhere between the 50 mile to 60 mile range in the electrified network, while a hydrogen fuel cell has a range of several hundred miles. We have a difference of application depending on route, geography and those kinds of things.

Baroness Brown of Cambridge: I wanted to ask Helen quickly: can you get the levels and rates of power delivery from both batteries and fuel cells that you need for a heavy goods train on an incline, for example, to get it moving from a stationary start, or are those particularly challenging areas?

Helen Simpson: You are absolutely right about power demand on rail. We are quite a high user of power and tend to take a significant load to accelerate a train from stationary. Particular numbers around a four-car multiple unit—an electric train—would be around 1 to 1.2 megawatts of power for that kind of train. For a heavy-haul freight train it is much higher and, as regards the fuel cell capability, you can get the power to the rail but it is about sustaining it and the range. I do not think that is a really practical application for the heavier-haul or higher-speed intercity routes. That is where we should be looking at electrification.

Baroness Brown of Cambridge: So we need a fully electrified railway if we are going to be able to put heavy loads on to it, basically.

Helen Simpson: The heavier-haul freight is a particular challenge. You can manage smaller distances with electrification through battery technology, but you will not manage accelerating a big heavy-haul train from stationary with 18 or 20 wagons of load behind it. We are going to have to think strategically about the rollout of electrification, and to work in the industry to deliver a plan that helps to do that. There are specific challenges around those two areas.

Baroness Brown of Cambridge: Thank you very much. That is very helpful.

The Chair: I will move on but I will come back to my question later on.

Q102 **Baroness Warwick of Undercliffe:** In my question I am coming back to aviation, so I suspect it is going to be directed at Paul Stein. In your presentation, Paul, you talked about the limits, effectively, on the use of batteries and fuel cells in aviation particularly in long flights, although you painted a very exciting picture of the prospects for short-flight aircraft. Could you say more about the long-flight prospects and just how much you expect to have to rely on carbon trading, because that seemed to be something that you were emphasising? Given that the Government have just brought forward the challenges in this area and brought aviation—and, of course, shipping—into their targets now, how will you

deploy your arguments with government? What is the way in which you will approach the 2050 target now?

Paul Stein: Thank you for the question. Could I unpack the two parts—what we are doing about the long-distance decarbonisation and what the measures are, and then perhaps the potential for the shorter range? Perhaps I could take the longer range first.

There is no technological reason why we would need any carbon trading whatever. If we can make enough sustainable aviation fuels by 2050, and the estimate is that we need 500 million tonnes of fuel a year—currently, 7% of all crude oil production goes into Jet A, the aviation fuel that we fill up our aircraft with—and so create enough of a global industry to supply 500 million tonnes by 2050, no carbon trading will be needed. The question is: is the world up for it and what will be the UK's role within that?

Clearly, it is not the aviation industry itself that will create that fuel. It is the great oil and gas giants, supported by technologies such as our small modular reactor programme and through renewable energy. But we are having to wind great companies such as Shell and BP, and Total in France, more and more into this SAF equation to work together. We have to work in lock-step with the regulators, aviation, the fuels companies and all the industry bodies, including our customers—the airlines—and their ultimate customers.

It is a case of moving the whole infrastructure and getting ready for it, with the backstop having to be carbon trading. Effectively, the target should be: can we receive 500 megatonnes? I have mentioned that everyone is of the view that we need a 20% to 30% fleet efficiency improvement, not just for the economic reasons I gave in a previous answer, but so that we can get down to just 500 megatonnes with the growth in passenger traffic that we expect to return post the Covid crisis. It is about connecting all the dots together, with more and more efficient engines and aeroplanes, massive ramp-ups in sustainable aviation fuels, working with the oil and gas companies, working with the international regulators, and the role the UK has as thought leaders and in creating nascent industries in sustainable aviation fuels.

May I make a short statement about the shorter journeys?

Baroness Warwick of Undercliffe: Before you do that, would you say something about the realistic timeframe that you and your company have in mind for that very ambitious programme?

Paul Stein: Perhaps one grounding is that IAG—International Airlines Group, including British Airways and others—made a statement just a week or two back, I believe, saying that it is going to move to a 10% blend by 2030. That is really good. It drives the market and means it now has to stimulate a global demand for a 10% blend. I think that sets the tone. Other airlines might kick in behind them, and that sets the journey. These sustainable fuels are drop-in fuels, so they are blendable. When you get up to 100%, you get net zero. When you are burning pure fossil, of course it is pure fossil. This is really a case of, as I said, working with

other industries; aviation has to link arms with the oil and gas industry to make this ramp-up happen.

Baroness Warwick of Undercliffe: Could you say something about short flights?

Paul Stein: I would like to link it, if you do not mind—forgive me if it does not fully answer your question—to a question earlier about stimulating a new industry in the UK. It really is very exciting. We have taken a stake as a company in a small start-up at Gloucester Airport called Electroflight. It specialises in the battery packs for aviation, which have to adhere to a very special safety standard. We are working with them to build an airspeed record attempt aircraft—a pure electric flight, which we hope to fly soon. Of course, this is to excite young people, create a new industry, and it is part of the buzz and excitement of this next generation of aviation as well as decarbonising.

Another great example in the UK is vertical aerospace. There is a start-up company in Bristol working on eVTOL—pure electric vertical take-off and landing—the next generation of helicopter with a number of exciting target markets. One that excites me a lot is air ambulance applications where you get to road traffic accidents far quicker and land in urban canyons in a way you just cannot do with a compound rotor helicopter. That is the kind of innovation that is being brought to bear and why a whole new industry is growing on the back of the utility of electric, hybrid electric and fuel cell flight, not just the decarbonisation.

Baroness Warwick of Undercliffe: Might I ask one final short point? Given that we are looking for recommendations that we can put to government, what would your main recommendation be to ensure that that particular development is encouraged?

Paul Stein: Obviously I have to start with the money side. On the pump priming, particularly in aviation, which tends to be quite long-cycle industries, the government funding is the make or break. The ATI—Aerospace Technology Institute—which I think you heard about on an earlier call, is funding the evolution of the longer-haul stuff, new engines and new aeroplane developments. It needs a separate block of money, a separate fund, to create all this third generation stuff and motor ahead in the UK. These are rapidly growing industries and in some parts of the world receive quite a lot of private equity funding and SPAC funding because it is seen as so exciting. The UK needs to join government funding and private equity to move this industry quicker than our competitors. It is ours to win.

Q103 **Lord Winston:** Could I turn to the comparison with other countries and ask if each of you could tell us whether there are particular challenges in your part of the industry that make deployment of low or zero-carbon technologies particularly difficult? What are the challenges there? Perhaps we could start with Helen Simpson on trains.

Helen Simpson: We have talked about the specific challenges of the size of our trains in the UK and our infrastructure. We have a space constraint that makes the rolling stock bespoke to the UK. The technology itself—

hydrogen battery for traction and train applications—is the same as other countries. Other countries probably have a clearer electrification strategy that is backed up by the funding. I know we have now developed a plan for decarbonisation that has been published by Network Rail, but the funding to support that electrification plan needs to be committed and seen through a number of years because it will take a long time to run through. We are talking about 10 years to roll through that electrification plan. It is about a commitment on that investment and support for it over time rather than a change and a boom-and-bust cycle for our supply base.

Lord Winston: Just to confirm, you do not see that there is going to be much future in electrification for goods traffic.

Helen Simpson: Rail freight?

Lord Winston: Yes, rail freight.

Helen Simpson: There will be a need to have electrified railway for the majority of rail freight, but there is a large and increasing market in the parcels and light logistics sector that could be adapted for other technologies such as hydrogen and batteries that we have been talking about.

Lord Winston: Ian Constance, could you tell us about road traffic and perhaps particularly about heavy vehicles?

Ian Constance: The biggest impediments to these things being deployed, as we have already touched on, are the charging infrastructure and the cost of the vehicles. Those are ubiquitous and all around the world. When you get into the heavier vehicles, though, when you talk about hydrogen particularly in fuel cells, there is a need for a clear hydrogen strategy. Some countries already have it, particularly in Asia. Japan has a very clear hydrogen strategy and understands where it is going. That enables a much clearer route to investing and putting in place the products that are required to go forward. Without that clear hydrogen strategy I think this kind of activity will stall.

Lord Winston: Very briefly, would changes in VAT make a difference for you?

Ian Constance: Taxation will be a massive issue across the board. It goes back to electrification. The way we tax vehicles, road fund licensing and fuel fund licensing will clearly need to be replaced somehow in the future, and consumers need to understand what they are going to pay and how they are going to pay it.

Lord Winston: Finally, Paul Stein, on air transport.

Paul Stein: On the comparison with other nations, I should start by saying the UK is in pretty good shape. We have the world's second biggest aerospace industry. We have a pretty good relationship between academia, industry and government, which is envied by some countries. We are not in bad shape. We have retained associate country membership of the Horizon programme, the EU framework programme,

which is funding some of the longer-term research in aviation. That is also helping.

I think it is fair to say that the US in aviation has more sources of almost irrational investment, if I could call it that, to go for these high-risk high pay-off ventures. DARPA and the Department of Defense quite famously spend quite a lot of money on exploring new avenues that have dual use, some spilling over into commercial applications and some for military use, and of course the availability of venture and private equity funding in the States is a far richer seam than elsewhere in the world.

I do not want to go around the world trading bloc by trading bloc, but I will mention China as a country that is able to fund quite a number of new directions in aviation. For us, it is very much having to keep our running shoes on and keep ahead of China's ability to fund its technology, which is going to be a challenge for the UK.

Lord Winston: Very briefly, could you tell us about manufacturing? Is that going to be a problem in Britain? Can we do more about the manufacturing side of these short-distance aircraft?

Paul Stein: Forgive me for using the phrase again, but I think there is much to play for. I have mentioned a company that I am very proud of, a little company called Electroflight, which is about 15 to 20 people in Gloucester. It has reached out to much of the manufacturing technology that Rolls-Royce has access to. One thing we have done well in the UK is to set up the High Value Manufacturing Catapult, which is a convening body of specialist manufacturing centres around the UK where small companies can come along and for a reasonable fee get access to world-class manufacturing capability, whether it is laser welding, additive layer or any of those methods.

We also need patient capital to build the manufacturing infrastructure in the UK. Having the technology is one thing, but earning money from the exports that come from the products is the second step. That is, perhaps, where a little more patient capital in the UK might need to support manufacturing.

Q104 **Baroness Brown of Cambridge:** I want to ask each of you what you think the primary safety issues from hydrogen and battery technologies are for your part of the industry and what the issues are that need to be addressed. I will start with you, Ian, because we have been hearing some rather frightening stories of Teslas crashing and it taking hours and hours to extinguish the battery fires.

Ian Constance: Those are unfortunate stories. I think we would put those down to early development issues. In general, the automotive industry has a very strong safety track record, and the development process that vehicles go through is very extensive to make sure they are safe.

In your prior session somebody made a comment that, if you were starting out from scratch with 80 litres of petrol driving around, people would say that was very dangerous. I think these are, in general, safe,

and the battery and hydrogen vehicles are made safe today. The biggest issue is that, when something goes catastrophically wrong, a new approach will be required from the fire service and the first responders, and they do not know how to do that. The other aspect of it is that the high-voltage systems in these vehicles are not something that your typical maintenance worker in a garage or workshop has an understanding of. It is about skills for the first responders and the maintenance people that I most worry about at this point.

Baroness Brown of Cambridge: It is just skills. They do not need any special equipment or different kinds of fluids to spray on these fires.

Ian Constance: Certainly they will need new equipment as well. That is absolutely right.

Baroness Brown of Cambridge: What about the hydrogen vehicles with very high-pressure tanks?

Ian Constance: Again, I think you heard from your earlier witnesses that the tanks are made to withstand a great level of torture and pain. Even when that happens, when they get ruptured, the safe venting of them can enable safe use of those systems in the worst environments.

Baroness Brown of Cambridge: Thank you. Let me come to Helen and trains.

Helen Simpson: I mentioned earlier that there is a rigorous safety approach in rail, and we need to continue with that. Some of the things that have been talked about such as how we design a train would be a little different because of the nature of rail. We would have a number of fail-safe systems in there. They are all built around the monitoring and detection of battery temperatures at individual cell level and being able to detect that early and prevent anything occurring. That is one of the things we talked about. The packaging of batteries is different in rail from other sectors because we have these higher levels of safety integrity for rail.

The other thing about hydrogen is that there are a lot of fail-safe systems there. The idea is to retain all the hydrogen within the high-pressure tanks. They are tested, as Ian said, to a very high level of pressure testing. The release and venting is done in a controlled manner and only in an emergency situation. Once hydrogen is in the air, it dissipates very quickly indeed. The risk is about containing it in a small area. For rail, that is thinking through how we operate hydrogen trains in tunnels and those kinds of situations, and how we do that safely. There has to be a very rigorous approach to that. It is all independently peer reviewed and assessed. Different people are looking at those things at the moment.

Baroness Brown of Cambridge: That is all under way and nothing has come up that looks insurmountable.

Helen Simpson: The design of the trains is under way, and that can be done safely. The design of the refuelling infrastructure can be done safely. There are plans in place to make those. The next challenge will be about scaling that up. We are moving towards a stage where we start to

think about the first passenger fleet of hydrogen trains or the first passenger fleet of battery trains in the UK, and what are the infrastructure and skills needed for refuelling trains with hydrogen. That is very different from what we do now. That is about training people, awareness and building up—I think the point was made earlier about the fact that all fuels are a high-energy source, and it is how we tackle and manage that risk and address it so that we are managing things safely.

Baroness Brown of Cambridge: Paul, I will come to you finally. You are used to extraordinary safety standards in the aviation industry. What is going to be new?

Paul Stein: That is a good question. The first new thing is that battery containment, particularly thermal runaway containment, has to go to another level over and above what can be tolerated on land and sea. Obviously, in an aircraft, you have to be able to contain any thermal runaway event on batteries. That means the required standards and level of engineering, and the required individual cell monitoring to meet aviation standards, go up another level from some of the other applications that we have heard about.

Hydrogen tanks, as has been said already, have to be able to meet all the various potential hazards that come with aviation. Accident integrity is one of the key ones, for fairly obvious reasons. I have said that some are exploring liquid hydrogen. If that route is chosen, there are some quite significant safety challenges, for example, in accident integrity, to make sure the cryogen cannot cause an accident. Hydrogen itself has an incredibly low flash point. Just brushing your foot on a carpet can set off a hydrogen cloud. To get to the required levels of safety is quite significant.

Electrification at altitude is another area. We are dealing with very high currents and very high voltages with those electric flight machines, and we are having to come up with whole new regimes to manage safety in the event of individual single point failure.

There are some less obvious areas that need to be looked at, which are not to do with the physical side but to do with the digital side. I mentioned eVTOL—electrical vertical take-off and landing. That will need digital flight control systems, fly by wire if you wish, collision avoidance algorithms for fairly obvious reasons, and air traffic management systems probably using artificial intelligence. We must not be blindsided by the safety regime around the digital side. It is almost as complicated as all the things we have to do on physical safety.

Baroness Brown of Cambridge: But you think it is all doable; there are no stoppers in any of this.

Paul Stein: Yes. Liquid hydrogen is the one where the jury is still out. I think the industry is saying, "We are still trying to find a way through how we would make such systems safe". The rest of it, I think, is doable.

Baroness Brown of Cambridge: There was a strong message certainly from the others about education and training here. Thank you very much.

The Chair: Mr Stein, coming from you, if you can, I hear that the French Government is thinking of possibly banning short-haul flights where the train journey is less than two-and-a-half to three hours. With high speed trains that is quite a distance.

Paul Stein: This would not be something that I would recommend the UK does. I cannot comment, if you do not mind, on why it is going down that path, but I can guess. To me, if a flight or a train are both net zero carbon, if the train is the better thing to use because it can carry more people in a more comfortable environment—and I am sure Helen has some great innovations to look after the passengers as well as the technology—people should be able to choose the train. If they want to connect a little faster through air, and it is the same carbon footprint, connect through air. If the EU is looking down that path, I do not think it should necessarily be mandating a particular transport mode.

The Chair: Mr Constance, we heard that your institution, the Advanced Propulsion Centre, is concentrating more on the battery side of technology and not as much on the fuel side of technology, and that you should be encouraged to do that. First, do you agree, and, if you agree, how could that happen?

Ian Constance: I do not totally agree. I would say that the vast majority of the funding that we are involved in goes towards battery technologies at the moment. On the fuel cell side and the low-carbon fuels, the aviation fuels for heavy transport, we would also support those kinds of approaches, and we do actively support those kinds of approaches. A fuel cell vehicle is still an electric vehicle, so it still needs batteries, motors and power electronics. We are covering that whole gamut. We would like to actively encourage more work on the heavy duty side to explore those paths that I mentioned at the beginning, and make sure we cover the whole gamut, and make sure that we have the UK selecting the best path.

The Chair: Thank you all three of you for coming today to help us with our inquiry. It has been most informative. Thank you very much. If on reflection you think there is something additional you might have said, please free to send it in. You will get a transcript to look over, and please comment or correct it if necessary, but for today thank you very much indeed for helping us.