Science and Technology Committee

Oral evidence: The role of Hydrogen in achieving net zero, HC1066

Wednesday 14 April 2021

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Watch the meeting

Members present: Greg Clark (Chair); Chris Clarkson; Katherine Fletcher; Mark Logan; Rebecca Long Bailey; Carol Monaghan; Graham Stringer; Zarah Sultana.

Paul Howell, Business, Energy and Industrial Strategy Select Committee, attended the Committee.

Questions 137 - 236

Witnesses

I: Gloria Esposito, Head of Sustainability, Zemo Partnership; and Dave Rowlands, Fleet Engineering Director, Wincanton.

II: Dr Helen McAllister, Strategy and Planning Director, Network Rail; and Mike Muldoon, Head of Business Development, UK and Ireland, Alstom.

III: Richard Clegg, Chief Executive, Lloyd’s Register Foundation; and Dr Morten Bo Christiansen, Vice President-Head of Decarbonisation, Maersk.

IV: Glenn Llewellyn, Vice President, Zero Emission Aircraft, Airbus; and Dr Brian Yutko, Chief Engineer for Sustainability and Future Mobility, Boeing.

Examination of witnesses

Witnesses: Gloria Esposito and Dave Rowlands.

Chair: The Science and Technology Committee continues its inquiry into the role of hydrogen in achieving net zero, today looking in particular at the transport sector—specifically, road, rail, shipping and aviation. We are very pleased to welcome from the Business, Energy and Industrial Strategy Committee Paul Howell MP.

I am very pleased to welcome our first panel of witnesses: Gloria Esposito, head of sustainability at the Zemo Partnership, which is an organisation that brings together Government, industry and NGOs in the purpose of accelerating the use of zero-emission transport solutions; and Dave Rowlands, fleet engineering director, at Wincanton. Wincanton is a supply chain solutions company that operates in the haulage space from 200 sites in the UK, with 3,500 heavy goods vehicles across the United Kingdom. Thank you very much indeed to both witnesses. Let me start with my colleague Zarah Sultana, who has some introductory questions.

Q137 **Zarah Sultana:** My first question is to both panellists. I will go to Gloria first. What role do you see for hydrogen compared to alternative low-carbon technologies for different road vehicles?

Gloria Esposito: Thank you very much for your question. We need to look at two timeframes: from today to 2030 to 2035, and the long term. There are currently a low number of hydrogen fuel cell vehicles on the road. There are a few hundred in the car market. We are beginning to see them in the bus market. The battery electric vehicle market has progressed much more significantly than hydrogen fuel cell.

We see a potential role for hydrogen vehicles where battery electric vehicles and battery technology might find it more challenging—for example, where there are longer routes. There is a lot of interest in using hydrogen in heavy duty vehicles, particularly in long-haul operations for those sectors that have high mileages and quite high power requirements. At the moment there are no hydrogen heavy goods vehicles on the market. That market is anticipated to begin to grow in the latter part of this decade.

Dave Rowlands: We see hydrogen as one of the fuels, but not necessarily a silver bullet. Clearly, we are developing electric vehicles at the moment. Electric vehicles are the predominant HGV-oriented power source alternative to diesel and other alternative fuels.

I agree with Gloria that the likelihood is that hydrogen is going to be more predominant in the heavier end, probably above 27 tonnes, in the articulated longer-haul sector. This country is effectively a regional haul country, but on that longer haul and heavier haul, we need a greater power base, without detriment to the overall weight of the vehicle, to uphold that payload and its efficiency. It has a heavier-end orientation.

I also agree that there are no hydrogen vehicles available today, certainly fuel cell vehicles. We are not looking for hydrogen vehicles to be using an internal combustion engine—burning hydrogen. We are looking at fuel cell vehicles, and certainly it will be post 2030 before any serial production comes on board.

Q138 **Zarah Sultana:** You mentioned that hydrogen is not a silver bullet. What is a silver bullet, in your opinion?

Dave Rowlands: I think we may need a blend of fuels. There will be some transitionary fuelling, perhaps more use of biofuels, until we get to the panacea of having a mixture of electric and hydrogen. It is going to be a difficult journey. Certainly, there is going to be a lot of need for developing the hydrogen side of the technologies, given that battery electric is developing but the hydrogen side simply is not there. At the moment we are just looking for the suppliers of the vehicles in order to get demonstrations of them, or an understanding of the technology and the other aspects that they will bring—the fuelling needs and how we will operate in the field with these vehicles on the highway.

Q139 **Zarah Sultana:** Gloria, do you want to come in on that point?

Gloria Esposito: I agree that a variety of options need to be available for different types of applications, whether they be urban, regional or long haul. We have a transitionary period in which we will have opportunities for other low-carbon solutions, in particular, for example, biomethane for long haul, but for city applications we can also see battery electric vehicles. There is a variety of solutions predicated on how the market and associated fuel and infrastructure are working. All three need to work together in this landscape.

Q140 **Chair:** I want to explore a bit the point about the mix of fuels. In the inquiry, the Committee has heard different views about the desirability of running different technologies together. The counter case is that you are just deferring a decision on which way you are going to go, and, in so doing—if you try to ride both horses—we need to decide whether we are going to have a viable hydrogen infrastructure or an electric infrastructure. What is your view on that, perhaps starting with Dave and then Gloria?

Dave Rowlands: I think we will need a blend. I do not see hydrogen as being predominant in the lighter end unless the technology radically changes. I think battery electric, provided we have the infrastructure for the electricity supply, is ideal for urban and inner-urban operations. I see battery being up to a weight limit of, say, 27 tonnes, as I mentioned, but certainly electric has a great advantage. It is clean and easy. It is understood and it is very safe, in safe hands.

We have been used to it. When I joined Wincanton 25 years ago, we had 2,500 electric vehicles. They were called milk floats. This is not new technology. It is just updated and improved technology. I see battery electric predominantly at the light end, certainly in vans, through to slightly heavier vehicles, but we need the energy content of hydrogen at the upper end, because we cannot afford to carry all the battery weight and technology on a heavier vehicle that will then diminish the payload. We need a balance between what we need from the fuels as opposed to necessarily backing more than one horse.

Q141 **Chair:** It is good to be reminded that battery electric vehicles for goods are by no means new. I should declare an interest as someone who learned to drive in a milk float many years ago.

Gloria Esposito: If we stick to heavy goods vehicles, we really need demonstration trials to understand how they will operate in real-life circumstances, and how the infrastructure associated with that will work. We need to understand the efficiency and durability of these vehicles. We need to understand the cost and the energy efficiency of the system. One of the constraints with hydrogen is that it has a number of inefficiencies in its production that makes the whole what is known as well-to-wheel efficiency lower than battery electric.

There are also challenges with storing and transporting hydrogen, because of its physical nature, that need to be overcome, and need to be understood in more detail. Trucks, especially long haul, have vast volumes of fuel that they need to transport, and it is really important we start to understand the practical, technical, economical as well as the health and safety issues surrounding that transportation. These demonstration trials are important.

Q142 **Chair:** Am I right in reading an implication into both of your answers that battery electric vehicles would be optimal were it not for the fact that for heavy goods vehicles they are not practical? In other words, is that constraint in the ideal use of batteries the window for hydrogen rather than its advantage per se?

Dave Rowlands: From what I am gleaning from the manufacturers, and obviously this is early days in the development of them, certainly batteries diminish the payload. Typically, a 17-tonne vehicle today using diesel would have a 10-tonne payload. A 17-tonne battery electric vehicle has a 7-tonne payload—the rest is battery. We have a payload constraint issue that, until battery technology improves—and it will improve—diminishes that payload. It also has to be charged more regularly and there are range issues. Certainly we will have to change the way that we do transport. We will need an infrastructure change for battery electric to even get it to the point where it might tip over into the 27-tonne network, where we perhaps go to hydrogen. Certainly there are issues with battery technology, but it is easier to manage and better understood at the moment than hydrogen, which is outside of academia but certainly very much in R&D for fuel cell on heavy truck.

Q143 **Chair:** Gloria, do you have anything to add?

Gloria Esposito: I agree with that. We also need to take into account the charging for those batteries. With greater energy density and size, they will have higher charging demands. That will place pressure on the local electricity grid as well.

For long-haul vehicles, hydrogen has capacity and space issues on a truck, and we have to ensure that that payload is not constrained. Once we have looked at storing large volumes on vehicles, we also need to consider how that is going to be managed so as not to impinge on the cargo load.

Q144 **Graham Stringer:** What about subsidy? How long would you need subsidy before hydrogen was competitive in its own right? Is that dependent on being able to use stored energy from intermittent sources?

Dave Rowlands: Given that we do not have a hydrogen vehicle at the minute even to trial, the learnings and discussions I am having suggest that even series production of a hydrogen fuel cell vehicle is around £500,000 a vehicle compared with a typical tractor unit at the minute being £90,000 a vehicle. There is a quantum leap in cost for each individual vehicle. That is in series production. I know that the economics will change, but we are not talking about a large fleet of vehicles. This is not a car network. This is a 45,000 market sell into the UK per annum, and half of those might be hydrogen oriented. It is nominally 20,000 vehicles, so it is not a huge marketplace to be able to get the economies of scale.

We certainly have to be given the opportunity for some pump-priming. Early pioneers and early adopters need some funds to be able to make them viable, because they are simply not going to pay back in their lifetime. Hydrogen and battery vehicles are likely to last longer. Typically, in our business, vehicles are four to five years of age before we dispose of them. The average age is around two and a half years. We are a very young fleet, so can adopt very quickly. The problem with the more expensive technologies is that they are going to have to be written down over the longer term to get that value back. They will be breaking even very much at the back end of their life, which might be year seven, year eight or year 10 even in hydrogen vehicles, and battery electric vans are only now starting to come down to a price where they can break even at the very back end of their life of, say, five years.

It is very much a different geography now as we get these high-tech higher-cost vehicles, and most certainly the industry would need some funding to get us to the point where more people are using it.

Q145 **Graham Stringer:** Can you estimate how long the subsidy will be needed for and how much it will be in total? I realise that it will be a back-of-an-envelope calculation.

Dave Rowlands: If you do the maths, it is a £500,000 vehicle that we have to buy, and on that premise there are a lot of operators out there looking to adopt it, but at the same time the infrastructure has to be there. If we are going to use hydrogen, we need the plant and equipment. It is not just the vehicle, it is the infrastructure. We have to go into this with our eyes open. I cannot see it being done in two years. There has to be a 10 to 15-year plan to get this to be the predominant heavy end of the fuel system.

Q146 **Graham Stringer:** How much is it going to cost the Treasury?

Dave Rowlands: You had better ask the Chancellor that. I deal with the steel end of the business, not necessarily the cost end. Somebody else better informed could answer that question, perhaps.

Q147 **Graham Stringer:** Gloria, would you like to try to answer the question?

Gloria Esposito: At the moment, hydrogen fuel cell trucks are more expensive. Hydrogen as a fuel is more expensive and the infrastructure is expensive. We need scalability in all those areas to bring the price down. That is going to take time.

It depends on the size of the operator as well. Very large operators will need that fuelling infrastructure at the depot and the smaller operators will need a network of refuelling stations across the country. These operators have very tight profit margins of two to three years, and they are going to need fast payback. It is going to take a long time for that to happen.

Until those economies of scale build, you are going to need those subsidies to make that price parity. The price of the fuel is very important to the cost margins of those fleet operators.

Q148 **Graham Stringer:** Is it going to be dependent on being able to utilise energy from intermittent sources stored in some way that is not obvious to us yet?

Gloria Esposito: I think that the key issue here is getting the production of green hydrogen or blue hydrogen over this time period. Over the next 15 years we need to have that scalability. Using it with intermittent energy storage is a slightly separate issue. The fact is that we need the supply chains to build up and we need to look at the infrastructure and how hydrogen will be transported, especially for the heavy duty goods vehicle market.

Graham Stringer: Dave, you were nodding.

Dave Rowlands: Diesel is just too good. It is just dirty. You can buy it on the street corner. It is available and safe. We have to have a similar network for hydrogen. In our fleet we buy 80 million litres of diesel a year, but half of that is bought through bunker stock on the roadside. Despite our own depot, we still need to buy fuel on the road. I know we are large and can perhaps invest in it, but 30% of our haulage is through third party subcontractors, and they are very important to us. The small hauliers have a major role to play. They will need to be picking up hydrogen on the road, not necessarily hydrogen stocks at their own depots. That infrastructure is very important for the national good.

Q149 **Graham Stringer:** Clearly, the Government's objective is to reduce the amount of carbon dioxide produced, but if you are going to use hydrogen fuel cells a lot of other, pretty noxious chemicals are involved. Do you do a full environmental impact assessment on the totality of the change to a hydrogen-based fuel?

Dave Rowlands: Wincanton has sustainability at the forefront of our mind and our customers also push it, so that sustainable element to any business discussion is back on the agenda these days. We will be reliant on the authorities, the Governments and the conventions across the world for truck production to ensure that that well-to-wheel analysis is being done. We tend to concentrate on the tailpipe emissions, because that is the end that we work at, but certainly as an organisation and through Governments and through associations in transport we will be looking to ensure that hydrogen is the right solution. They always have some concerns about some areas of it, and certainly we as a business would prefer to use green hydrogen, albeit that we would want very blue hydrogen if we had to use blue, ensuring that carbon capture is at a level of the high 90s as opposed to any lower than that. Yes, we take it into consideration, but we are reliant on a lot of others to ensure that it is right at the point where we purchase it.

Q150 **Graham Stringer:** A final question from me. Is it realistic or is it science fiction to get over the problem of having to carry very heavy batteries the whole length of the journey—you could do it by recharging the batteries by either having overhead wires on motorways or wires by the side of motorways? Is that realistic or is it pie in the sky, rather than wire in the sky?

Dave Rowlands: I am sure Gloria will chip in, but Wincanton is involved in a catenary project for overhead wires—tram trucks, let us call it—for certain parts of motorways. As I said earlier, there is not going to be one silver bullet here. There could be opportunities across some of the straight haul on some of the motorways that are very urban to have some catenary, for instance. That is an option.

Charging on the road is a problem for heavy truck because it needs so much energy at one point over a short period. That infrastructure for heavy truck charge—150 kWh up to 300 kWh—is not on every street corner. That is where heavy haulage and pick-up on the road for battery-operated vehicles is more problematic.

Gloria Esposito: A demonstration trial in Germany is looking at overhead catenary, and it can offer a very efficient way of charging, especially along the road system, but, as has been pointed out, the flexibility of the vehicle will obviously be limited and we need demonstrations to touch on that.

You mentioned life-cycle analysis and looking at environmental impacts. That is critically important in understanding not only the carbon impact but the other environmental impacts associated with a range of different technologies and fuels.

Q151 **Carol Monaghan:** It is interesting that both of you are talking about the shift towards new technologies. There has to be a certain reticence or a bit of insecurity about whether to make that jump to new technologies. What should the Government do to manage this uncertainty? How can they encourage companies to take that leap or encourage investors to put their money into it?

Gloria Esposito: As I mentioned earlier, demonstration trials are critically important. The Department for Transport is looking at this with regard to hydrogen and battery electric vehicles for heavy goods vehicles. That is critically important, as I said, in giving operators the confidence to make that decision. It is really important for them to understand the total cost of ownership, the durability and the fact that these vehicles can do the work that they require. I think having those demonstrations is a key point.

Q152 **Carol Monaghan:** Dave, do you have anything to add?

Dave Rowlands: We need a number of things. This is not an easy move from the very long-established fuel of diesel. We most certainly need leadership from the Government. We need infrastructure to be developed in parallel with the vehicles as they become available. We have been trying to get the gas network as an industry to be an infrastructure that we can use in various places. It has taken 25 years to get to where we are now. There are very few gas stations for methane, for instance.

We need pump-priming for fleet purchases. That is going to be so important, as I mentioned earlier. It must not disadvantage those early adopters, because there are some major investments here, with very little return. Transport is a commodity-based business, so every pound goes straight to the consumer or it goes as a saving to somewhere else because we cannot compete. We are very commodity based. Certainly, the subcontractor hauliers, if they are reliant on haulage as their only income, are looking at 2% to 3% margins, and they just cannot afford to invest. We need the certainty of that investment.

We need flags from the Government to ensure that that certainty is there for 10 or 15 years for any green fuels investments, tax breaks or fuel duty reductions. Anything that we can do, we need to have a long-term view of it, not just a typical five-year or 10-year aspect of what we are doing.

We need incentives for good eco behaviour. If we are using hydrogen, please allow us to use longer vehicles, heavier vehicles. Look at this as being an opportunity of a carrot to say, “If you use something that is ecologically good, you can have a greater benefit that brings other efficiencies, not just the use of the fuel.”

Finally, I would like the Government to invest in safety investigation. When we talk about hydrogen, from the discussions I am having with manufacturers, there is likely to be around 95 kg to 100 kg of hydrogen on board a vehicle, plus a battery of about 90 kWh to 100 kWh. There is a lot of energy on board that vehicle in a tank. I am not seeing a lot of research on the safety of that on the road. I would like the Government to be looking at doing some academic research, not just desk-bound but some testing of that. Typically, hydrogen is in a controlled environment at the minute. It is in manufacturing plants. It is handled by people where it is in their safe hands. When it is in the public domain, it is a very different product or element. Where you just have fuel stations on the roadside, hydrogen is an untapped knowledge base. We need to understand the safety aspects of using it on the road and accident issues that can occur on the road and leaks, and then build that into the growth of the fuel, so that the rules, regulation, administration and protocols are there before we put the vehicles into work.

Q153 **Carol Monaghan:** Dave, you talked about this idea of developing both the vehicles and the infrastructure in parallel. In some ways, we have a blueprint in the development of electric vehicles. Do you think that has been a good example of development in parallel where we have a few vehicles and a bit of infrastructure, and we have seen it develop, or have there been sticking points on that?

Dave Rowlands: One problem we have with the charging infrastructure is that there are so many people trying to pull electricity for their own needs, whether it is heating or other technologies. There is not enough power to certain points in cities and other places where we have distribution centres. In that respect, it is not necessarily a good model to go for. We just have to run very hard at it. The electric network is going to be under massive demand. I think that one of your witnesses the other day mentioned that we use 300 TWh of energy today. It could double when we start to have an electric environment for cars and vans and suchlike. We really need to run at that because we will not have enough energy to put into the vehicles if the infrastructure is not there, whether it is on the road or depot based. I think that the model is right, but we need to run harder at it.

Q154 **Carol Monaghan:** Would that be your recommendation when we are talking about the development of hydrogen—that we fire everything at it and get more serious? I think the difficulty is that, if we jump in with both feet and find that hydrogen is not—we have already mentioned the phrase—the silver bullet, is there the potential that we could invest a lot of money in something that is not going to deliver what we expect?

Dave Rowlands: That is always a risk, but you back the horse you want to back. I would urge that we have multiple fuelling opportunities, not only because we do not necessarily have the silver bullet in one but also because of resilience. I have a concern that the whole infrastructure for transport could be reliant on electricity supply. It would be prudent to have a hydrogen supply as a back-up, or indeed, to ensure that we have resilience. We need to look at the whole strategy of our fuelling in this country so that we pick more than one means of having car, van or truck move on the road, to supply the goods to the country.

Q155 **Carol Monaghan:** I think that is a really good point. A lot of the discussion, not necessarily in this Committee but generally, is about one versus the other, VHS versus Betamax. Your recommendation is not to back a single horse.

Chair: Is that assent, Dave?

Dave Rowlands: Yes.

Q156 **Carol Monaghan:** Could I have Gloria's thoughts on what the Government should be doing to support the development?

Gloria Esposito: We need really robust evidence to understand how the deployment of hydrogen will materialise for heavy goods vehicles, especially under long-haul operations. There are different ways of storing and transporting hydrogen, whether that is compressed or liquefied. At a future time, it could be injected into the gas grid.

We need to understand how this would all work, how we get scalability, what the costs are, what the energy requirements are, and, going back, what the health and safety implications are. We need to see whether we have the skill base to ramp up this roll-out of infrastructure.

All these areas need scrutiny to understand how they would materialise, and, over time, how that would be scalable, given the vast amounts of fuel that the long-haul sector uses and its intense requirements in its duty cycles.

Chair: I am going to go to Paul Howell now. He wants to start with the declaration of a historical interest.

Q157 **Paul Howell:** For good order, I should say that the last permanent job that I had before coming to this place was as logistics director of a manufacturing company, and Wincanton was the supplier of our logistics at that time. Obviously, it is historical and it should not have any influence, other than the fact that it might inform the questions I am just about to ask.

I very much empathise with Dave about having a network of suppliers. Wincanton would deliver for us nationally, but it would use local suppliers to cover more local routes. We need not just the guys who can afford to have a bunker of fuel but a network and infrastructure of fuel.

That is the direction in which I would like to take the questioning. We have talked about the different pieces of infrastructure. I will come to you, Gloria, first, and back to Dave afterwards. It sounds to me as though the infrastructure we should be looking to put in place almost has to be strategically directed because there are certain areas of transport that it is almost inconceivable hydrogen will be able to supply in the heavy end and the long-distance end. It is more like covering gaps where electricity cannot. How do you do that as a strategy in developing an infrastructure?

To roll that a stage further, particularly for the bigger companies, it is not just about this country, and trying to cope with the differences in moving around London versus Manchester versus going up to the far reaches of Scotland. There is a thing called Europe next to us, with different countries, with different strategies and all that sort of thing. I know we have done Brexit, but we are still trading with them, and there are still lots of vehicles that have to go across there. How do we need to align ourselves with European strategies as well as ensuring we do all the different pieces of a UK strategy? That was a bit wordy, Gloria, but would you like to have a stab at answering that?

Gloria Esposito: Interoperability is obviously critical, especially when you have long-haul vehicles going over to the continent. From the manufacturers' perspective, many of the manufacturers are, in fact, European and are working with fuel suppliers and infrastructure suppliers in that partnership. That partnership work is really important, but it is also essential that individual countries have their own strategy and own process of developing infrastructure. That is going to be challenging because you have to have everybody working together. Not only do you need the infrastructure, but, going back, you need a green supply of hydrogen at low cost to make it affordable for these operators—so, yes, that interoperability is critical.

Q158 **Paul Howell:** Is there anything you would like to add, Dave?

Dave Rowlands: I agree. As I said before, we need the harmonisation of standards across Europe, across the UK and across the globe. American and European standards clash at times. We have to have a global standard for this because this technology cannot be developed by one country alone. We most certainly need to be part of the development of it for the jobs in this country. I am very conscious that Wincanton as a UK-listed company is interested in jobs in this country. The development of those trucks at the minute is not in this country. We have one manufacturing plant and it assembles—it does not develop. I am conscious that we have to be aware of all the standards across the globe, but we also need to be doing something on our own turf to develop technologies and therefore employ people.

Paul Howell: I will leave it at that.

Chair: Thank you very much, Paul.

Q159 **Chris Clarkson:** Turning to infrastructure again, I quite liked Carol's analogy of VHS versus Betamax, and I am old enough to get the reference. Could HGVs make use of the electric charging infrastructure that has already been built for cars? I am thinking in particular of some of the larger cities. I am an MP in Manchester, where we already have charging points all over the place. How feasible would that be?

Chair: Gloria, do you want to kick off with that? The connection was a bit distorted but I think we got the gist of it. Can the electric charging infrastructure be used for hydrogen?

Gloria Esposito: No. I think we will need a completely different type of arrangement because of the health and safety issues surrounding hydrogen. Long-haul vehicles are going to need to store significant volumes of hydrogen. We already have a growing network of gas refuelling stations, both CNG and LNG for biomethane. Those stations could evolve into green hydrogen or low-carbon hydrogen refuelling stations over time, but we have to anticipate that the size of the stations will need to increase, and there are obviously challenges around how to scale them up.

Dave Rowlands: Predicated on the basis that those charging points are able to charge electric trucks, it is problematic because they are too low a power supply. They might be 75 kWh, and in the heavier end we will need 150 kWh to 300 kWh of energy at the plug. It is not going to be on a street corner. The expansion of car charging would probably be prohibitive in most cases beyond a van. Car charging is not accommodating the space for the truck in any case. It is going to have to be a parallel network or, perhaps, a consideration for truck when those charging points are installed. Certainly, again, that infrastructure is so important for electric vehicles.

For cars filled with hydrogen, it is the ability to have energy at source. The hydrogen is likely to have to be compressed to get it into a truck, on the premise that that truck hydrogen is likely to be at a much higher pressure to get the energy content on board. There are huge engineering issues to consider just for the infrastructure, never mind the actual vehicle.

Q160 **Chris Clarkson:** If we are looking at a hydrogen-based network, we have already discussed the fact that infrastructure will be developed alongside the technology. Would a small number of strategically placed hydrogen refuelling stations be sufficient for road freight needs or would we need a much more detailed infrastructure plan?

Dave Rowlands: We pick up about 40% of our fuel on the road, so we need more than 10 or 20 strategically placed sites. This needs to be a national network for every town and city, or even village, to have the certainty of refuelling. Whether that is electric at higher kilowatt-hours or hydrogen, there is going to be a need for it. Obviously, the main freight network is where the predominant draw will be for the heavier vehicles, so hydrogen needs to be on the freight network, but do not be surprised where the trucks go and where they will need fuel from.

Q161 **Chris Clarkson:** If we are going to use that network, how significant is the need for high-purity hydrogen to the ability to use the gas network, because there, of course, we are talking about a mixture?

Q162 **Dave Rowlands:** In terms of hydrogen, we cannot have a mixture of gas, so it is a separate network. We cannot co-mingle the different gases. The network pick-up point could be the same place. We could have hydrogen, gas and methane at the same place, and they are used to that technology and the safety aspects of it. It would be sensible and prudent to have multi gases at a refuelling point and potentially some electricity as well because we will need that for compression needs. The fuel court of the future will likely be larger and more important in that it has multiple numbers of fuels available to us.

Gloria Esposito: In the future we could see hydrogen being injected into the gas grid, but for hydrogen to be used in a hydrogen fuel cell it has to be at a purity of 99.9%. It is very high purity. That hydrogen would need to be purified at the refuelling station. That has an energy, a cost and a size implication for that refuelling station. We could end up in the future where we have a gas grid that has methane, biomethane and hydrogen.

All of these bring about immense complexities in the supply of those different fuels.

Q163 **Chair:** I will round up this fascinating session. We are very grateful for your evidence. You have been very clear that we would need a pretty comprehensive network. A dozen or two dozen refuelling stations is not going to be enough for Wincanton's needs, and I dare say that would be true for other competitors. We heard at the beginning of your testimony the view that battery electric vehicles are likely to take the strain for the lighter vehicles. It is principally the weight and the range that constrains the size of the batteries that are required for heavier goods vehicles. That leads to a dilemma, does it not, because, if you are to build a substantial network infrastructure, the returns on network infrastructures are over many years, but battery technology may advance, both in weight and range, to shorten the period of relevance for that infrastructure? Whether it is, as Carol said, your investing in something that may turn out to be a white elephant, ultimately, or whether you are looking to commercial companies—as I imagine you would at least in part to finance such infrastructure—is there not an essential difficulty that very expensive and extensive infrastructure is needed for something that might be ephemeral in its use?

Dave Rowlands: That is an obvious concern. On that premise, we have to have certainty for the future that that investment will be made available. The electricity network is going to be invested in anyway. That is a given. You could say that battery electric is the safest bet. Battery technology will improve and get lighter for a given output. The electric network is the safe bet. However, we still have the problem of carrying that energy on board a truck on regional haulage and long haulage. Manufacturers are telling me—and we go with guidance from those who ought to know their products' application—that hydrogen is the right fuel.

That is the information that we have available at the minute. The dilemma with hydrogen is that it is a completely new network. There is very little of it and there will be other demands on that hydrogen for other things, whether it is the gas grid or otherwise. I do not have all the answers. We are putting a lot of questions up. Certainty for the future would be very useful if someone said, "Yes, we are backing hydrogen for the next 50 years and we have a view that we might as well start developing it." If someone says, "We are still sitting on our hands and we are not sure what we are going to do about hydrogen," nobody will invest.

Gloria Esposito: From the OEMs' perspective, there seems to be no preference at the moment between those two technologies. Manufacturers are looking at both options.

We need a paradigm shift in battery chemistry to improve the energy density and lower the weight and size of batteries. That might not happen for another 10 to 15 years. As Dave says, there are many unknowns. That is why having resilience and a variety of options may be needed, especially in the short to medium term.

Chair: That is great. Thank you very much indeed to both our witnesses, Gloria Esposito and Dave Rowlands, for giving us a very detailed insight into some of the challenges in the road vehicle use of hydrogen in the future. We are very grateful for that.

Examination of witnesses

Witnesses: Dr McAllister and Mike Muldoon.

Chair: We are now going to welcome our second pair of witnesses to talk about the potential use of hydrogen in railways. I am pleased to welcome Dr Helen McAllister, strategy and planning director, Network Rail, and Mike Muldoon, head of business development, UK and Ireland, Alstom. Alstom is a rolling stock manufacturer, and a third of all the daily passenger rail journeys made currently in the UK are on Alstom trains. Welcome to both of you. Perhaps we can start with my colleague Chris Clarkson.

Q164 **Chris Clarkson:** My first question, to Dr McAllister, is about the role of hydrogen in rail. National Rail's decarbonisation strategy concluded that under 5% of the network would be best served by hydrogen at the moment. To what extent could technological developments affect that?

Dr McAllister: Thank you for having me here today and thank you for your question.

We have done some further work on what would need to be true for that level of hydrogen requirement to change. We have come to the conclusion that it is unlikely to significantly change over the next 30 years or so. The constraints for hydrogen usage for rail are the quantity of hydrogen that would need to be stored to power a service, and the extent to which technology would need to evolve to power a long-distance high-speed train or a freight train would be such that it would make it uneconomic to use it.

It is not so much about technology improvements. It is about the volume of hydrogen. You can compress hydrogen and you can carry more of it—work is being done in that area—but it is unlikely to be to the level that would make it viable for something like a heavy freight train or a long-distance high-speed train.

The question about how much of the network hydrogen technology can support being zero carbon is more about how we specify what the outputs need to be for the network for zero carbon. If you need zero carbon overall for rail, freight needs to be zero carbon, long distance/high speed needs to be zero carbon, and hydrogen is not, as we see it at the moment, the answer to those questions. However, it is a really important part of the mix in getting to zero carbon for the network.

Q165 **Chris Clarkson:** It is part of a wider tapestry.

Dr McAllister: Yes.

Q166 **Chris Clarkson:** Mr Muldoon, how does Alstom see the international market for battery and hydrogen trains? Is there a huge demand for this technology? Are you looking actively at developing and researching this?

Mike Muldoon: Yes, absolutely, we are developing this. Alstom has been developing hydrogen trains for about eight or nine years. We put the world's first trains into service in Germany in 2018. We have four orders for trains to be put into passenger service—two in Germany, one in Italy and one in France. We are certainly seeing a relevance to the technology, and a significance to it, which backs our decision to start developing it that time ago.

Picking up on Helen's comments, we see it as part of the mix necessary to decarbonise the network. Previous speakers talked about a silver bullet. It is not a silver bullet. Rail has the benefit of electrification. It is a very well-known and well-demonstrated technology in our sector, and is a very great tool in the battle to decarbonise the network. We see hydrogen as having a role, and, potentially, a greater role than is currently envisaged.

As we naturally give the benefit of the doubt to future development of batteries, we should look to other technologies to develop over time as they are adopted more widely. As we go forward, we may see a shift in the exact proportion of the network that uses whichever technology. The important thing is that what Network Rail's work has done already is highlight that in 2050 there will still be a necessity for hydrogen trains on the network if this is to be net zero. We need to focus on that and start progressing towards it.

Q167 **Chris Clarkson:** Is that consistent with the model we have seen developing in other countries such as Germany, for example, where they are pursuing this mix?

Mike Muldoon: Yes, absolutely right. The sector that hydrogen is developing most readily in at the moment is regional passenger trains—trains that are not running on high-speed, high-intensity routes. It is absolutely right that they do not suit that technology, and electrification should absolutely be deployed in those areas.

Where we see the growth is in regional operation and some mixed use, so using hydrogen to give you a significant extension of operation beyond the end of the electrification section. A train might be electric for most of its operational distance and use hydrogen to bridge the gap. Batteries are also used in that role, but we have the same constraints as the road sector—the weight and the volume of space required for batteries. The problem that Helen just described as applying for hydrogen is worse for batteries in many ways, because they are heavier per unit energy and they are bigger per unit energy.

Q168 **Chair:** Before I go to Rebecca Long Bailey, I have a couple of follow-up questions, perhaps to Helen. Chris asked you about the assessment that about 5% of the networks could be served by hydrogen. That embodies a solution in a sense that electrification is the first best. I think that 5%

covers areas where it is difficult to electrify. Is that the case?

Dr McAllister: It is not so much that electrification is best. Each individual technology is best in the area that it addresses. Hydrogen does not require lots of expensive infrastructure compared to electrification. It is a great technology from that perspective, as is battery. However, because of the quantities of fuel that you need, and the parts of the network that those trains run on that would need that, electrification is the best option for those specific areas. At the moment, electrification is the best option for freight. It is the best option for long distance high speed. It does not mean it is the best option for the network as a whole. It just happens that the areas of the network that hydrogen is the best option for is around 4% or 5%.

There is also the potential to use it as an interim technology in areas that would not be electrified until later on, more towards 2050, so you could realise carbon savings earlier by using hydrogen technology in the interim.

Q169 **Chair:** But you would not be converting electric lines to lines that hydrogen trains use. There is no sense of running hydrogen trains on electrified lines.

Dr McAllister: Currently, we are not looking at converting electric services into hydrogen services. If we had hydrogen trains, would they run potentially underneath the wires in some areas? I could not say yes or no at this point, but we are not talking about converting electric services to hydrogen services.

Q170 **Chair:** Understood. Mike Muldoon, you mentioned local and regional trains in Germany. Are they replacing diesel trains, or are they running in areas that have been running electric trains up to now?

Mike Muldoon: They are only replacing diesel trains. We are not seeing any interest from anybody to displace electric trains. Delivering energy to the train by wires is by far the most energy-efficient means of doing so, and gives you great scope to have very powerful and fast trains. That is why they suit high speed and freight so well. No, we are not seeing any evidence of that at all. It is all about removing diesel from the network in countries just like ours, where there is a relatively high proportion of the network not electrified and a difficult economic case to justify doing it.

Q171 **Chair:** Thank you. That is very clear. You gave the example of the trains in Germany that you manufactured. Did you do that on your own accord, as it were, using your own resources, or was it subsidised by the German Government, or some other source of public subsidy?

Mike Muldoon: Yes, to all those things. We invested significantly as Alstom, but partners in regional and national authorities in Germany were involved as well. We are seeing in many nations a degree of what was described earlier as pump-priming being deployed by Governments who have vested interests in the ability to move people around their countries. We recognise some of this as not just decarbonising rail but decarbonising travel. One thing we need to do is have a rail network that is demonstrably clean to attract the modal shift on to the railways that we would all like to see. We will then get collateral savings from the other modes of transport that are not being used. Every person who gets out of their car and uses a train makes a significant saving overall to carbon. There are lots of perspectives there that feed into the way authorities are supporting the activity.

Q172 **Chair:** Was that subsidy for the development of the technology, or is there an ongoing subsidy for the use of that hydrogen train?

Mike Muldoon: There was some contribution to the development, but, predominantly, what it comes down to is the fact that the cheapest option for rail is to continue using diesel. If the authorities adopt new decarbonised technology, inevitably they import extra costs, as we discussed earlier. Meeting those costs, you might argue, is a form of support to the process that those authorities are providing, but effectively it is couched as a long-term operating model, and the trains are deployed for 25 or 30 years. The typical life design of a train is 35 years, so they are a long-term commitment to a long-term product.

Q173 **Chair:** Are you able to say what the contribution from public funds was to the development costs of that German project?

Mike Muldoon: I do not have specific numbers that I can give you.

Q174 **Chair:** Do you know what your own company's R&D costs were for it?

Mike Muldoon: Broadly speaking, yes. They were significant. There are tens of millions of euros involved in the development of any new product. Businesses such as Alstom, and many other OEMs around the world, of course, are investing consistently in where they think the product portfolio needs to go, and that is what we are doing with hydrogen.

Q175 **Chair:** Finally from me on this, would you be investing in demonstrating the technology in the UK absent Government support—in other words, on a commercial basis—or would you not do it unless it were publicly subsidised?

Mike Muldoon: We have been making our own investment in the UK. We have been developing a form of product for the UK market, looking, in fact, at converting trains for hydrogen traction. Together with our partners in Eversholt Rail, we have invested in that programme.

Q176 **Rebecca Long Bailey:** Thank you to both of you for speaking to us today. First, Dr McAllister, you have already alluded to the volume of hydrogen available restricting deployment. In your view, what very generally is needed from Government to enable the initial deployment of hydrogen trains? When do these decisions need to be made to reach the decarbonisation targets?

Dr McAllister: There have been successful trials of hydrogen trains on the continent. In the UK, the industry has demonstrated prototypes and trial runs of hydrogen trains. We have kind of got the technology to work. Everything set out in the traction decarbonisation network strategy is predicated on rail requiring to be at, essentially, near-zero carbon emissions by 2050, and anything within that strategy is based around that output requirement. How many hydrogen trains we need to deploy, the extent of hydrogen on the UK network, the extent of further electrification and the extent of battery trains are all dependent on understanding what direction, and how quickly, we need to move towards net zero for rail. We are working closely with DFT on the transport decarbonisation plan. That will help set out what that strategy is for surface transport overall.

Answering the questions on how quickly, and when, and what we need, is very dependent on what the end point needs to be. If we need to be at zero carbon by 2050, the driver of the hydrogen requirement for the UK network is not as much the end-state carbon reduction for 2050, because that is around 4% or 5% of the network, and you could start that later. We can realise carbon savings now by introducing those trains. We do not have to put wires up over huge swathes of the network to realise those carbon savings. It is a relatively low infrastructure requirement, but it will take a few years to bring about.

The next step is for UK rail to say now, "Let us run some of these services in anger. Let us see how we run an actual passenger rail service powered by hydrogen on the UK network." Industry is there, investing and looking at prototypes, and ready to take that step. Our recommendation is that we start doing that sooner rather than later—that we start considering those decisions, as I know industry is having those discussions with Government now about how we take that next step. There is no significant infrastructure investment required compared to electrification. The infrastructure requirement is essentially electrolysis plants around depots, so it is relatively discrete. I think that demonstrating that we can run those services on the network is the next step.

Q177 **Rebecca Long Bailey:** Mr Muldoon, your company has previously said that it continued to invest in this technology without any external support and was waiting for Government approval to deploy it. You have alluded to that again in your responses today. What actions and support would you like to see from Government, and within what timeframe? For example, would you like to see similar levels of support to the German project, or the other asks that you have been making of Government?

Mike Muldoon: Just to reiterate, I think we are in a position now where we are ready to move to the implementation step of deploying fleets rather than demonstration steps or prototypes. That is the case in the UK market now, certainly on behalf of Alstom.

As Helen just said, this is about a long-term perspective. The decision partly needs to be, "We commit to the plan." That is "we" at a collective national level. Helen's team has produced an incredibly detailed and viable strategy. Commitment to it allows businesses such as ours to commit to developing the technologies to meet it, and that would help with this process.

The commercial structuring of the railways in the UK is quite unique, compared to that in Europe at least. The process of procuring that operation, and how it relates to a rail operator, how it relates to the Department for Transport's role in franchising, or whatever the future is going to be to replace franchising, is a little difficult to speculate on at the moment because that is the subject of the Williams review, which, as we know, has not yet reported on the rail sector.

We are a little unclear about the detailed decisions, but the fundamental decision needs to be to say, "Yes, we accept now that this strategy is what we need to achieve." We also need to build in the review processes that the strategy itself recommends so that we can take stock at certain points. We need to progress.

One of the imperatives is not only choosing what we are going to do about replacing diesel. The problem we have is lots of the diesel trains on the network are approaching the end or have reached the end of their design life. They are very old. They predate emission control, so they emit quite a lot of unpleasant fumes. Most importantly, there is an imperative to replace them, practically speaking. There is a very limited market now or desirability to invest in diesel trains because people now know they do not have a long life in that they could not serve more than half of their design life. What we need now is commitment to this plan so that investors and businesses can react to it properly.

Q178 **Rebecca Long Bailey:** On the bigger industry picture—this is a question first to Dr McAllister—Network Rail has suggested that the combined nature of transport systems' use of hydrogen fuels in more vehicles such as buses, for example, might make combined fuelling stations a viable possibility, which would lead to economies of scale. To what extent does the long-term viability of hydrogen use for trains depend upon deployment within other sectors and upon shared infrastructure?

Dr McAllister: The way we have worked up the strategy so far is that it does not, really. We have based the requirements for hydrogen trains, essentially, on producing hydrogen very close to the point at which it is needed, primarily for the purpose of fuelling those trains. If industry is going to partner organisations that will set up electrolysis plants next to depots, then it is likely that there would be more hydrogen produced than is required by the trains themselves, that we could therefore be an anchor client for that set-up, and that hydrogen can then be used in other industries. At the moment in the strategy we have assumed all those costs in with rail, so we are not dependent.

If it can be combined with using multi-fuelling points with other forms of transport, or hydrogen that is used for other sectors, that will improve the business case. It is an upside, right-sided failure for us, but we have assumed stand-alone at the moment.

Q179 **Rebecca Long Bailey:** Similarly, Mr Muldoon, Alstom has said that hydrogen trains would be ideal for creating highly predictable long-term demand that would help to develop commercial hydrogen production.

How much would your company’s plans depend upon the bigger picture of hydrogen deployment in other sectors, and, again, the implementation of shared infrastructure?

Mike Muldoon: I would agree with Helen in many ways. We do not see ourselves necessarily as dependent, but we think there is huge merit in combined aggregated use of the production facilities. It allows sharing of costs across multiple modes. The bigger volume that can be produced, the better the price that we all pay to use the hydrogen.

You can perhaps imagine a scenario where very few people want to travel from a station to a station. They have the first leg and the last leg of their journey to complete. One of the beauties of hydrogen is that it suits particularly well return-to-base fleets. You have one fuelling point and the vehicles go out and come back to the same place. That is the model that the trains would operate—so might taxis, for example. You might be able to have a carbon-free taxi solution that people can use, or other forms of transport—minibus, bus, whatever—which means you can put together a multimodal carbon-free journey.

I think that offers quite a lot of attraction. We see this a little bit with the proposed hydrogen transport hub for Teesside. The plans for that programme are built around the aggregation of multiple streams of demand, but certainly we are finding that the offtake that rail needs—a small fleet of trains will require tonnes of hydrogen a day—gives good anchor demand for such facilities and benefits as much the other modes as it benefits ourselves.

Rebecca Long Bailey: That is really helpful.

Q180 **Chair:** There are a couple of points on which it would be useful to have your perspective. Is the maximum speed for such hydrogen-powered trains as are being developed 100 mph? If so, what is the reason for it?

Mike Muldoon: Thus far, yes. That is partly because that is the sector we are targeting. I mentioned regional trains earlier, and, typically, that is the fastest speed diesels would operate in most parts of the world. The UK is fairly exceptional in running them faster. The reason is that when you carry energy with you, the faster you go, the more energy you need. We all see it in our cars. If you want to go far, you drive gently and smoothly, and you do not go at speed. Rail is the same. The faster you go, the more energy you need. If our issue is carrying energy, it is sensible to design to the strengths of the technology, accepting that electrification is stronger for higher speed. There is nothing in theory that would stop you producing a very fast hydrogen train. It is just the faster it goes, the less distance it goes. That is what we see very much with electric cars and electric vehicles as well.

Q181 **Chair:** It is that same balance we heard about in the previous session.

Mike Muldoon: Yes.

Q182 **Chair:** Does that extend to weight as well? You talked about regional passenger trains. Again, I do not think there is a working example of a freight hydrogen-powered train. Am I right in that?

Mike Muldoon: Correct. However, there are developments starting around the world. I know that OEMs are looking at this challenge. A key underpinning assumption for our electrification plans in the UK is the necessity to electrify for freight. In Canada, for example, there is work going on to look at what the options might be for long-distance rail freight using hydrogen, but it is early days in its development. The power and range requirements for freight are very challenging for any form of stored energy.

Q183 **Chair:** I noticed Dr McAllister nodding. Do you agree with that analysis?

Dr McAllister: I do, yes. In theory, you can use hydrogen to move a freight train. You just need an awful lot of it and you need to take up the space that is carrying the cargo with hydrogen. That is the problem rather than any lack of capability of the technology.

I would also add that in America and Canada you have very different set-ups for freight on rail than you do in the UK and on the continent. The trains are much bigger and much longer, so you have a different commercial proposition than you do in the UK and in other countries in Europe. A solution that works for Canada and America is not necessarily transferrable to the UK.

Chair: Thank you very much indeed.

Q184 **Paul Howell:** To warm up, I will come to you first, Dr McAllister. I want to make a little declaration of interest, I suppose, in the sense that my constituency is right next to Teesside, so, yes, I am very interested in the hydrogen work going on there. Hitachi Rail is also based in my constituency, so I have engagement with the rail industry in that space.

I know from those discussions that we get into wanting more. I know you have touched on that terminology already in terms of where we are. You have talked also about only 5% of the rail opportunity being associated with hydrogen. I would like to understand how much of that is pure hydrogen, and how much of it would involve multimodal, whether that is bimodal or trimodal solutions. It seems to me that 5% is still a significant part of the rail network. What quantum of actual investment in hydrogen trains means that you are going to get the level of standards, experience and knowledge that goes around running those fleets? What level will make it viable by having enough of the market, so that it does not just become an electric and battery solution—it becomes electric and hydrogen, or whatever, to get the space? How many trains do we need to make it a worthwhile business sector?

Dr McAllister: For the first part, the strategy work that we did looked at single fuel trains for simplicity. It is a question of: where does electrification work; where does hydrogen work; where does battery work? We have made recommendations on that basis. However, that does not mean that there will not be requirements to have bimodal hybrids, whether that is hydrogen electric or battery electric. I feel that that is very much a bottom-up decision that needs to be made when you are looking at the services that need to be run, and how quickly you are going to be introducing technologies. I would expect there to be hybrid solutions by the time we get to 2050. It is just that that is not how we approach the strategy for the sake of, frankly, completing it and making sensible recommendations.

On the quantum of hydrogen being around 4% or 5% of the network, that would increase if we also looked at interim hydrogen solutions between now and 2050. We have done market-sounding exercises as part of the strategy work. The feedback in general was that the level of service that we are proposing is feasible. It is not too small, whatever too small looks like, but it is on the small side, and it is likely that it would be an evolution of existing trains that are converted for hydrogen, or can be used for hydrogen battery, rather than designing a completely new hydrogen train for the UK market. I think that is absolutely sensible.

In terms of having the base of competence and expertise to do this, the hydrogen services will be quite geographically specific, and I think there will be enough requirement in the geographies that the train is being used in to keep that level of expertise, training and competence to be able to operate those fleets. It is not 4% scattered randomly across the network. It is 4% in concentrated areas that will allow that to develop.

Q185 **Paul Howell:** I get that. I had not thought of it that way, but I appreciate the clarity. That is a useful explanation of the fact that it could be 50% of the trains in a specific area as opposed to being 4% across the country.

I am a little surprised that you do not see the bimodal option. To me, at a simplistic level, not a knowledge level, if we already have electrified railway lines, but the trains running on that space are getting into difficulties because you cannot get the electric overhead wires, by using bimodal hydrogen or something else there could be an extension of the range of a hydrogen-based train that could massively impact on the viability of more decarbonisation of railways as opposed to hydrogenisation, if you follow my logic. Do you want to comment on that? Then I will come to Mike to see whether he wants to add a comment.

Dr McAllister: Absolutely, I fully agree with you. Hybrids will absolutely be a part of the solution to decarbonise the railway. In the strategy work that we did, it is incredibly difficult to model that and to come up with an overall business case. We had to make a number of simplifying assumptions. One of those simplifying assumptions was that you either have an electric train, a hydrogen train or a battery train, for the sake of the modelling. In practice, I absolutely expect hybrid trains to be part of the solution.

Q186 **Paul Howell:** Mike, would you like to build on that?

Mike Muldoon: Generally speaking, I quite agree. Sometimes we over-obsess about modes of operation and over-endow products with capability. If we look at overall efficiency again, and how we get the best from these vehicles, the less equipment that is not functioning that we carry with us, the better. If we carry a redundant traction system, be it a battery, be it hydrogen, whatever it is, under the wires, we are using more electricity when we are under the wires, and when we are off the wires we have all the kit associated with transformers and other things used for electrification, so we diminish our overall efficiency in both modes.

That said, that is often outweighed by the benefits. It will boil down to the nature of the service being offered and how infrastructure issues align or not to service offerings that operators need to offer. I agree with Helen. Inevitably, there will be a mixed set of solutions. We see this in Europe with the hydrogen trains we are developing already. One design is pure hydrogen, and then we have a couple of designs that are hydrogen and electric biomodes.

Paul Howell: That is very helpful. Thank you to both of you.

Q187 **Chair:** You have been working on trains in Germany and elsewhere on the continent. You have pure hydrogen and you have hybrid. Does that mean that were we in this country to go down the hydrogen route, at least in part, we could simply use the designs that you have already got there—we do not need to start from scratch—or is there something particular about our network that would require a re-engineering, as it were?

Mike Muldoon: Sadly, the scale of our railway is slightly smaller than the European one. I think that is the best way of putting it. When we talk about gauge, many people think about the spacing between the two rails on the ground. We have something called the loading gauge, which is the hole in the air the train has to go through, if you can imagine that. That is defined by the size of tunnels, the positioning of signals, the positioning of railway platforms and other things beside the track. When the Victorians led the world and built the railway in Britain so extensively, they set a size of train that was smaller than we see in Europe. Some of the packaging issues that we have been talking about already—we heard in the previous session about getting space for hydrogen on board a vehicle—are a greater challenge in the UK than in Europe, because we have less space that is not dedicated to passengers.

We have overcome that over the years with packaging diesels and diesel electric bi-modes and other things. Ultimately, the laws of physics dictate the space necessary for the energy storage with hydrogen. That is where the challenge comes in. While we would take the same core elements of technology, and the same learning that has been developed elsewhere, we have to redefine how we fit it into the train, and be a little smarter about it perhaps, you might argue, to achieve an efficient package for the UK, while still giving the range and performance that we want.

Q188 **Chair:** Is that part, Dr McAllister, of Network Rail’s plans? Is there a recognition that we will need different rolling stock?

Dr McAllister: There is a recognition that we will need different rolling stock from that we have today, but we have not gone into the detail that says, “The rolling stock that is being developed and trialled on the continent is this, and we think that the additional cost of accommodating that on the UK network would be this.” We have assumed that there would be a hydrogen train that fits on our network.

Q189 **Chair:** That work would need to be done if we are to pursue this avenue.

Dr McAllister: I think so. I would expect any hydrogen trains for the UK network to fit within the gauging of the UK network and not require extensive gauging works to be accommodated. I think this is a question that would be solved in the rolling stock manufacture rather than railway infrastructure.

Q190 **Chair:** Mr Muldoon, did you want come back in?

Mike Muldoon: I was going to say it is always our job to make the trains fit, very rarely the other way round. The Victorians did a brilliant job of building it all. We cannot go changing it now.

Q191 **Chair:** Dr McAllister, are you confident that we could establish pretty quickly the need for a bespoke fuelling infrastructure for the rail industry, accepting that there might be other linkages to other forms of transport? Is that feasible within a reasonable timeframe?

Dr McAllister: In the context of a small number of years. It is not something we could knock up next week, but over a four, five or six-year period we would need to establish exactly where that location is required. Broadly, we know now, but exactly where, and then there would be the question of whether it can be accommodated at a depot, and whether there is land available. Those standard project development processes would need to be gone through in order to do this.

Q192 **Chair:** Can you say something about how refuelling works in Germany, and is contemplated in France and Italy?

Mike Muldoon: Each of the operations will have its own dedicated fuelling facility designed and built for the purpose. The schemes that we have developed so far in the UK are based on a similar approach. It means we in the transport sector and rail sector are working very closely now with colleagues in the energy sector. We have not been obliged to or needed to do that in the past. We have been working to understand the issues around siting and operating these types of fuel stations, and how we will meet the needs of the train fleet.

It is quite an exciting aspect of this deployment. It is new development and new skills and the long-term operation of future technologies in areas that generally do not benefit from such things. Often the routes in the areas we are talking about are industrially remote, or disadvantaged, so it is a great way to introduce this kind of expertise. If we then see it spreading in other areas, to buses and lorries and other forms of vehicles, or heating—wherever hydrogen crops up—the skills are very transferrable. It is a good way to deploy.

Longer term, of course, ultimately dedicated fuel facilities are going to be more expensive than if the gas main happens to be filled with hydrogen. Even if we have to purify hydrogen on site and put it into trains, that is easier and simpler than making it on site.

Q193 **Chair:** Dr McAllister, we have talked about the estimate that 5%, or thereabouts, of the network might be best served by hydrogen. In a world in which we have a legal obligation to get to net zero, what is the alternative if we were not to pursue the hydrogen solution? What would be done by the rail sector?

Dr McAllister: The immediate alternative is electrification, because where hydrogen will work electrification will work. That would be more expensive. That assumes that you have the same service patterns as you do today and you give the same level of service to passengers. If we needed to change that to hit zero carbon rather than the technology type, there would be things that you could do with, I guess, battery trains to take people on short journeys, but we have not considered that. Some of the lengths we are looking at where hydrogen would be deployed are such that you would have to have pauses to recharge them. It would be a suboptimal solution for passengers, to deploy that instead of hydrogen. The technology that would give passengers the same experience would be electrification if we did not use hydrogen, and that would be more expensive.

Q194 **Chair:** I do not know whether you caught any of the previous session when we were talking about roads and heavy goods vehicles. Obviously, batteries are prominent in road vehicles. Is it the case that, even if battery technology in terms of weight and the distance that it allowed were to make progress for heavy goods vehicles, we are talking about an order of magnitude of difference in terms of what would be required to power a fully laden freight train?

Dr McAllister: Yes, you come down to the same problem that you would still need to take up a chunk of that freight train with the batteries required to power it. At the moment it does not look feasible to be able to use batteries in the future to keep a freight train moving in the same way as it moves at the moment, as far as we can see.

Q195 **Chair:** Does Mr Muldoon want to come in on that?

Mike Muldoon: We concluded the same. This is why we started developing hydrogen in the first place. Our initial studies suggested that to give the same performance as the German train that we have been operating—a 90 mph train, give or take, with a range of about 600 miles to 650 miles a day between refuellings—we would need a battery that weighed about 33 tonnes. Aside from all the issues of manufacturing such a thing and charging it, that constrains our ability to carry anyone. It is both heavy and very large. It is an order of magnitude change.

At Alstom we produce battery electric trains, and you have to optimise the best possible range versus the weight and space penalty that you carry. That current technology gives about 100 to 110 miles, and is probably the best compromise range you can achieve with existing technologies. It is a big leap to give equivalence to what hydrogen can achieve.

Q196 **Chair:** Dr McAllister, against the obvious attractions of having two alternative technologies, networks, and the resilience that comes from that, there is the cost that, potentially, you are not making as much progress by putting all your resources into a preferred technology. Given that electrification, as you have said, would be the alternative if hydrogen were not pursued, have you considered whether backing a single technology would be more effective than spreading, perhaps thinly in the case of two technologies, the investment that would be required?

Dr McAllister: We have not modelled that, but we based the strategy work we have done very much upon the decarbonisation taskforce work that was carried out that identified the battery, hydrogen and electrification technologies as the appropriate ones to help decarbonise the rail network.

I can understand that just saying, yes, it should all be electrified feels like a very easy thing to say. We know how to do electrification in the UK. It is compatible, therefore, with the trains that run at the moment. However, even in terms of 4% or 5% of the network for hydrogen in addition, with an equivalent source from battery, you are still talking a few thousand single track kilometres. That is still a significant amount of electrification work that would need to be done. Electrification, even if it is done as efficiently as it possibly can be, is still expensive. There are great capital cost savings from using hydrogen and battery solutions over electrification solutions.

There is also, if you need to reach zero carbon by 2050, the capability of the supply chain to be able to deliver the level of electrification that is required. The traction decarbonisation network strategy recommends over 13,000 single track kilometres of electrification between now and 2050. We are already stretching the supply chain significantly to be delivering at rates greater than have been delivered in the past, for a number of years, and throwing another few thousand single track kilometres of electrification into that mix with a fixed end point of 2050 does not feel like a sensible thing to do. From both that deliverability perspective and the cost perspective, I very much think that we need a mix of technology solutions to get to net zero.

Q197 **Chair:** As a benchmark, Dr McAllister, what is the benchmark cost per kilometre or per mile for electrification?

Dr McAllister: It depends on where you are electrifying. We have set out ranges in the interim programme business case of up to £2.5 million per single track kilometre. A load of underpinning assumptions sit behind that. It is not that any project will cost this. This is over the course of 30 years. If there is a programme of this extent, that is the order of magnitude that we are looking at.

Q198 **Chair:** It would be reasonable to infer that the places that have not been electrified are more difficult places, and, therefore, might be higher cost than the average cost of electrification to date.

Dr McAllister: Yes, especially when you are looking at high-frequency passenger services. The bits that are simple and cheap to electrify are the ones that we have done already.

Q199 **Chair:** I am very aware that cheap is a relative term when it comes to civil engineering on the railway.

Dr McAllister: Yes, please note that is a very relative term.

Chair: Indeed. Dr McAllister and Mr Muldoon, we are very grateful for your evidence today. You have helped us think about some of the challenges and opportunities of the use of hydrogen in the rail sector. Thank you for your time this morning.

Examination of witnesses

Witnesses: Richard Clegg and Dr Christiansen.

Q200 **Chair:** We are now going to turn our attention to shipping. I am very pleased to welcome our next panel of witnesses: Dr Morton Bo Christiansen, the vice-president and head of decarbonisation at Maersk, the largest shipping company in the world; and Richard Clegg, chief executive of the Lloyd’s Register Foundation, a charity that supports science and engineering research in the areas in which the Lloyd’s Register—clearly associated with shipping—is active. Thank you very much indeed for joining us today.

Would you help us with one thing to start with? Ammonia is talked about a lot as a potential source of power when it comes to shipping. We have been talking about hydrogen a lot to date. Dr Christiansen, perhaps you might say a bit about the relevance of ammonia, and how it should be considered alongside hydrogen.

Dr Christiansen: Thank you for inviting me to this session. In shipping, with the way the technology is right now, we cannot use hydrogen directly as a fuel for our vessels. It is simply impractical. It would take up too much space and there would not be enough space for the containers that we are carrying.

We need to find a carrier of the hydrogen. For that we are looking at two promising fuels. One is ammonia, as you mentioned. Basically, you take the hydrogen, you add nitrogen and you get ammonia, which is a gas. Alternatively, you can use methanol as a carrier of the hydrogen. Instead of nitrogen, you take some biogenic CO_2 and make methanol, which is an alcohol. It is a fluid and is therefore much more practical to handle on a vessel. You can also make methanol from biomass, which does not involve hydrogen directly.

Both of those are quite promising, and the methanol part is the most mature for now. We have announced that we will launch a vessel in 2023 that sails on carbon-neutral methanol. The engine technology is ready and the safe handling at sea of methanol is relatively straightforward. There are a few problems to be solved, but they are not huge.

Ammonia is bit further out in the future, simply because there is not an engine today that can burn ammonia. The engine designers are working hard on that, and they expect to have one out in 2024.

Further out in the future, fuel cell technology looks quite promising for ammonia but it is really hard to see when that will be ready at the scale we need. The thing about big container vessels is that they need very powerful engines, and today you simply cannot make a fuel cell that delivers 60 MW, as we would need.

Ammonia is definitely a very promising future fuel. It has some challenges in that not only is it a gas, it is a toxic gas. If you inhale ammonia you will die. It will also pollute the ocean if there are spills.

An alcohol is very different. You do not have these concerns with it. The big advantage with ammonia in the long run is that the feedstuff is almost infinite. If you can get enough renewable energy, you can produce ammonia from water and air. You can also do that with methanol, but it is much more expensive to extract the CO_2 than it is to extract the nitrogen from air. Nitrogen is 78% of atmospheric air, and CO_2, although way too high, is only 400 ppm. For the e-methanol, as we call it, to make it feasible economically, you would need a point source—a paper mill or something like that where you could take it from the chimney.

Q201 **Chair:** That is a very helpful introduction to the technology. Is it fair to reflect that industrial production is mature for ammonia, whereas to make it practical for your purposes there is some development needed when it comes to methanol?

Dr Christiansen: Today, the market is at zero for green fuels. You can get lots of ammonia and lots of methanol, but it is all made of natural gas. We do not want that. With the huge ammonia plants you have today, it is relatively straightforward to replace your hydrogen, which today may be made from fossil fuels, with green. It is the same for the big methanol plants; it is possible.

For biomethanol, the technology at scale is more immature. We do not have any really big plants. The biggest plant is in Canada, where they make methanol out of municipal waste.

The real challenge for us as an industry is not about the engines or the vessels; it is about producing the fuels at a cost that our customers can accept. It will be more expensive. The challenge we are looking at is scaling these things at a price point that is acceptable to customers.

Q202 **Rebecca Long Bailey:** Thank you both for coming to speak to us today. There has been lots of discussion on preferred low-carbon fuel choices for shipping. We have already heard this morning about methanol and ammonia, both their promise and the environmental risks. What are your views very generally on the most viable low-carbon fuel choice, both environmentally and economically? Are there any other technologies with long-term viability for decarbonising shipping that do not depend on hydrogen? We have already heard about methanol and ammonia this morning. Other examples could be the potential to improve batteries to make electrification viable for deep sea shipping. I wanted to hear your general views, again starting with Dr Christiansen.

Dr Christiansen: If I start with the last point about electrification, we have a rule of thumb almost that for anything electrical there will need to be an available sea lane. The problem is that these vessels can weigh anywhere between 200,000 tonnes and 300,000 tonnes. They typically need to cover 10,000 nautical miles. Propulsion by batteries with today's technology will take up way more than half of the load of the vessel, which will entirely kill the financial viability of electrification. We will either need significant disruption in this space or deep sea applications.

There is also the whole charging aspect. The amount of power you would need to charge batteries like that would be very significant.

For more regional routes and what we call short sea there could definitely be a path. It is just not yet. For marine applications it is hard to see that path in the foreseeable future. There are many uncertainties, as you are also mentioning.

With regard to environmental impact and so on, all other things being equal, methanol is a simple alcohol. If you can produce it in a sustainable way, it is less risky. But when it comes to that, if you do it from biomass, there are certain things about the life cycle of biomass if you make it from the CO_2 source, where you either need to take it from the air or ensure that the source you get it from is biogenic.

There are many constraints. The way we think about this is we do not have the perfect solution. I do not think there will be one winner. I think we will see a portfolio of different options you can choose between when you design a vessel.

The thing is we have to act now. We cannot sit and make studies and mature the technology for another five or 10 years. The planet simply does not have time for that. We are looking at what can be done now. We are very excited that methanol is a solution: it is there now, and we can do it. We will soon start building our first vessel. We will ramp up production with partners on the fuels. We can get started. Let us see 10 years from now what technology will offer us. I am sure it will offer us something that no one here can even imagine. We just need to get started. We are looking at every single case of fuels individually and from a full life-cycle analysis perspective, otherwise you just risk pushing the emissions elsewhere in the value chain.

Q203 **Rebecca Long Bailey:** The same question to Mr Clegg: what are your views on the most viable low-carbon fuel choice for shipping?

Richard Clegg: Dr Christiansen covered some important points. I would like to pick up on the timescales and about needing to start now. If we are going to reduce CO_2 levels to 50% of 2008 levels by 2050—within that timeframe—we have to have ships with new propulsion systems going down the slipways within this next decade, with the national and international distributor infrastructure to support them, recognising that shipping is a global distributed industry. This is a decade of action. That is an important point.

I reinforce the point that Dr Christiansen made: it is a portfolio of technologies. As was said in one of the earlier panels about cars, there is no silver bullet here. Ships operate in different environments and carry different cargoes, in different situations, and the economics and the technologies will be different choices.

It will be a portfolio. There are a number of lower or low-carbon things that can be in that portfolio. Energy efficiency is an option, but that is never, ever going to achieve all the zero-carbon ambitions. Higher fuel costs will help the economics a little bit but are not going to get us there by themselves.

All the fuel types that we have been talking about—ammonia, methanol and hydrogen—are based on hydrogen economy, so that is the root feedstock.

We have been talking about electric. The point that Dr Christiansen made is bang on. Ships operate off grid. The distance from Shanghai to Rotterdam is 12,000 miles. These ships are carrying 20,000 containers. There is just not the space on them for an enormous battery capacity. Current technology is not feasible at scale.

There are, for example, short routes such as ferries that can and do run off batteries already. For niche applications, it is this portfolio business.

There is a nuclear option as well with molten salt reactors. They are capitally expensive but have much lower operating fuel costs once you have sunk the cost into them, although there are public perception issues, and there is hybridisation as well.

Q204 **Rebecca Long Bailey:** That is really helpful. Lloyd's Register did a study in 2019 that stated that the challenge of deploying ships that could use net-zero fuels was dwarfed by the challenges of getting the right fuel ready and the necessary support and infrastructure on the land. This is the $1 million question: do you think the industry should settle on a specific set of fuel choices and focus on them? If so, what support would you ideally like to see from Government to be able to deploy these fuel sources at scale?

Dr Christiansen: You are absolutely right. We have been building vessels for hundreds of years. Our first vessel was a steam vessel, so we have already changed propulsion once in the lifetime of our history. That is not the challenge. The challenge is to scale these fuels.

To put things into perspective, methanol is one of the most commonly traded, if not the most commonly traded, chemical commodity in the world. Annual production is 100 million tonnes. If our fleet was to sail on methanol alone—that would not be the case, but just by way of example—we would need more than 20 million tonnes, and that is just our fleet. Container shipping would suck up the entire market today for methanol. That market, by the way, is grey methanol, so it is made from LNG or natural gas. We need to scale up the market massively.

That is another reason why we need to think about this as a portfolio. We need all the methanol and ammonia players in the game. We need everybody who can muster up production capacity to get this going. When you look at it, that is a little bit of a breathtaking scenario, but, on the other hand, it is also a business opportunity. It is an opportunity for many countries across the world. There is so much money that wants to go into this, if you can find an uptaker. That is really what we are seeing. One of the reasons we have leaned in and said we are going to start is simply this chicken and egg type situation that we have with a lot of projects on the drawing board. We are talking to projects on six continents. They are ready to go. All they need is a bankable uptaker, who says, "Yes, we will buy that, and we will buy it at a certain price." That is what can unlock this, and then we can get started. That is the challenge we have.

To your point about what Governments can do, I think the story you have in the UK with offshore wind is a brilliant example of how a visionary Government can do something and completely move the needle on offshore wind. We need to give the developers a regime with stable boundary conditions, and help investors to de-risk their investment.

In particular for the e-fuels, both ammonia and methanol, when you look at the costs today, they are quite high. Biomethanol can probably be made cheaper, but the e-fuels just need to run down the same cost curve that offshore wind, solar panels, batteries and what have you have gone through. Obviously, Government can help to get that started by providing an environment where perhaps they can support some of that cost. I really think that your own story with offshore wind is a brilliant example of how a Government have really made a difference here and moved the needle.

Q205 **Rebecca Long Bailey:** Mr Clegg, the same question: do you think the industry should settle on a set of fuel choices, and what should the Government be doing to support that?

Richard Clegg: Lloyd's Register has been supporting the global maritime industry for 261 years. We have been here before. The world has been here before in terms of transitions. As Lloyd's Register, we have supported the transition from wind to steam, and from steam to fuel oil, and now this transition.

The thing that is really different about this transition is that all the normal drivers are absent. There are no drivers around fuel abundance or fuel price. There are no drivers around energy density or safety. The driver is purely societal; therefore, Governments have a key role to play. If you scrape the varnish off it, it boils down to the Government creating the ecosystem and the expectations and the incentives for this transition.

That is around policy. Policy needs to be largely technology agnostic but to drive the industry down certain pathways. It needs to create demonstrators for uptake and early adoption, particularly involving international partners. This is not the UK going solo on any of this. It has to be the international demonstrators. There should perhaps be green corridors as well, again, to show that the ecosystem can work, and an encouragement of investment in infrastructure, particularly the land-based infrastructure.

I would like to pick up on something that Morten said a moment ago about UK offshore wind energy. Potentially, that provides an opportunity for the UK as well around using this renewable energy for the production of clean hydrogen. There is an opportunity there, because that could be a more cost-competitive option than importing hydrogen, and could give the UK an opportunity, either as an exporter of hydrogen and/or a preferred maritime bunkering location for maritime fuels in Europe.

I would say something very quickly about ammonia as well. There is a lot of ammonia production in the world. There are plants coming online in Saudi Arabia and Australia. Australia is setting itself up as a green exporter of hydrogen to Asia and Saudi Arabia. The global ammonia manufacturing capacity would need to double to meet 30% of the needs of the world's shipping fleet. There is something about scale there.

Q206 **Rebecca Long Bailey:** Thank you, Mr Clegg, that is really helpful.

Finally, I have a question on targets. I am sure you both know that the International Maritime Organization set an objective to reduce emissions by 50% by 2050, compared to 2008 levels. On the UK's specific targets, the Government have said they expect all new ships that are built for use in UK waters to be zero emission by 2025. Do you think that from where we are at the moment development is on track for new net-zero ships by 2025? More generally, and another difficult question to answer: what is the maximum level of feasibility for retrofitting existing ships for net zero by 2050?

Richard Clegg: Ships were never designed—their materials, their safety, and even the capacity that they have available for carrying the fuel vector, whatever it is—for retrofitting. Retrofitting is probably going to be technologically and economically a non-starter. What is needed here is this surge towards new ships coming down the slipway that have been purposely designed and fuelled for this new era.

Q207 **Rebecca Long Bailey:** Thank you, Mr Clegg, that is really helpful. Dr Christiansen, the same question to you.

Dr Christiansen: If you consider the situation we are in as a real emergency, which we do, certainly if you want to get even close to a 1.5 degree science-based target for our industry, although they have not been published yet, the way it looks is that you will have to start retrofitting. There is no way we can get to halving our emissions by 2030 without retrofitting. We cannot see that path for now. Of course, it is not the ideal solution, but we are looking into ways in which it could be done. It depends a lot on the fuel. I do not think it will be feasible to retrofit for ammonia operations, but given that methanol is an alcohol, it means you can put it to *[Inaudible.]* because methanol is just an alcohol going into the water and it does not actually pollute.

Chair: Dr Christiansen, we lost your sound briefly. Rewind a few moments, if you would not mind.

Dr Christiansen: I was speaking about retrofitting and, indeed, it is not ideal because our container fleet is designed for bunker operations. For methanol it is definitely doable technically. We are looking into the costs. It is too early to say, but there looks to be a path that could be pursued. It would obviously not be for the oldest vessels and so on, but I do not think we should rule it out entirely. If we want to halve our emissions by 2030, which is far from what the IMO has set as a target—if you believe in the science-based target approach—we will need retrofitting to some extent. That is at least how we see it now, but we are working very hard on different pathways on how we can get the most reduction or abatement for every dollar invested.

One point to put in here is that we have talked a lot about the role of Government and the IMO, and so on. It is not a secret that our company thinks that the IMO should be more ambitious. The way we are seeing this, certainly for container shipping, is that it will be the companies and our customers who will be leading the charge. The dialogue we have with our customers is very constructive. They acknowledge that there could be a premium, and a lot of them are willing to pay that premium to solve the problem. In container shipping we are blessed with some customers that are the big branded business-to-consumer companies, and they are really feeling the pressure from their customers. They have set targets for their scope 3 emissions, and their supply chains are a significant part of their scope 3.

Regulation or not, of course we should do whatever we can to get a level playing field and to incentivise the right behaviours. We support that 100%, but we believe that, in partnership with our customers, we can move this forward quite significantly, because there is a demand for this. Our customers want to have decarbonised logistics solutions, and I find that very encouraging.

Q208 **Rebecca Long Bailey:** That is brilliant. Mr Clegg, did you want to come back in?

Richard Clegg: I agree with Morten about retrofitting, particularly for methanol. It is not going to be a total solution, but it is an intermediate step. As Lloyd’s Register we have been involved in retrofitting vessels, an example being a ferry called the Stena Germanica, which has been in operation for five years now, retrofitted to methanol.

I would like to add a point. You were mentioning, Rebecca, the IMO and the ambition to reduce CO_2 levels globally from the maritime industry by 50% compared to 2008 levels. You are quite right that that is held up as a polestar to navigate by, but there is no pathway to get there. The point is that this is an international challenge and it requires an international solution. It requires all the players to come together—regulators, Governments, investors, infrastructure owners, shipowners, shipyards, ship operators.

One thing that we have done with Lloyd's Register, because of who we are and what we stand for, is to create a decarbonisation hub that brings all these players together. This is a social investment for the benefit of society, bringing all these people together, to look at the different pathways to impact—where is the evidence, where is the insight to choose between them, and what are the steps to get down them—so that we can start to go down some of these pathways for decarbonisation as a co-ordinated action through the decarbonisation hub.

Q209 **Chris Clarkson:** You have both indicated that building land-based infrastructure is a bigger task than its maritime equivalent. Mr Clegg, you have already talked about the need to get some of these new net-zero ships going down the slipway sooner rather than later. I would be interested to hear the extent to which you think any infrastructure should be put in place in advance for net-zero fuels, depending on what that mix is, and what we decide to go with?

Richard Clegg: You are quite right that going to net zero is not just about the ship; it is about all the land-based infrastructure and the supply chain that goes into fuelling the industry. The challenge is, as we sit here today, that nobody knows which fuel type to choose. Nobody wants to invest in one fuel type, only for the rest of the world to go in a different direction, leaving them with stranded assets, and things like that.

Many of the leading fuel vectors—ammonia or methanol—are hydrogen based. Those fuel types are hydrogen carriers in one form or another. It is hydrogen bonded to nitrogen or hydrogen bonded to carbon as regards methanol. I think that an early investment in hydrogen-based infrastructure is the direction to go. That is an early move that can be started.

One of the challenges is that this all has safety considerations. There is the potential option to be explored of offshore, particularly linking with offshore wind farms, which could have generating and storing, and potentially bunkering, facilities offshore as well. The point is, in terms of early investment in infrastructure, it is the feedstock that feeds many of these technologies, which is hydrogen.

Dr Christiansen: I was kicked off my wi-fi and I did not hear the question, so my apologies for that.

Q210 **Chair:** To paraphrase Chris, the question was about whether the land-based infrastructure for the supply of fuels is perhaps an even greater challenge than developing the ships, whether new build or retrofit.

Dr Christiansen: The larger container vessels do not actually bunker very often. We design our vessels so that, if you take an Asia-Europe round trip, they typically bunker only once. It means you do not need a lot of infrastructure. You need some hubs, but, in principle, you can make do with one in each region. That would probably not be practical, but a big advantage of container vessels is that we do not have to stop for fuel that often.

With methanol, there is a safety challenge in that it has a lower flash point than we normally allow at sea. Other than that, it is a liquid that can be handled with known technologies, mostly.

It is a bigger challenge with ammonia because it is a toxic gas, so there is more work to be done there. We are doing a lot of that. Just last year here in Copenhagen the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping was founded. It is an independent, not-for-profit research organisation that is sponsored by the foundation that owns the majority of Maersk. It is looking into the more long-term or systemic challenges that will need to be solved.

We as a company are looking into solving the methanol problem 10 years ahead because we need to have a solution by 2023. For methanol, nothing is easy, but it is definitely doable. Ammonia is more difficult, but we also have a bit more time to solve it, given the technology maturity.

Q211 **Chris Clarkson:** I want to pick up on something Mr Clegg said. You talked about perhaps being left with stranded assets, depending on what mix of fuels or what type of fuel is used. To what extent will the UK have to align with low-carbon fuels adopted internationally?

Dr Christiansen: Again, I think we will see a host of different solutions out there. The risk of having stranded assets is of course a scary one when you operate long-life vessels, as we do. Current vessels can be retrofitted for methanol. It is a matter of cost, of course, but stranded assets can be avoided.

The most important thing is flexibility and that you allow all the technologies. Of course, they need to be safe, but we simply need a portfolio of technologies, otherwise we are never going to be able to scale to the level that we have to.

The infrastructure-related challenges are much more related to other parts of shipping—tankers and bulk carriers and those sorts of vessels. They are more like taxis, whereas container lines are more like bus lines. That is not the case for the other parts of shipping, so I think there will be more challenges to solve.

Q212 **Chris Clarkson:** Mr Clegg, is there anything you would like to add?

Richard Clegg: I would just reinforce some of those points. The maritime industry is a global distributed industry. The UK is a pixel in that picture. Whatever the UK does has to be supportive and integrated into that bigger picture. The UK cannot plough its own furrow and do something itself. International co-ordination and integration are needed. It goes back to what I was saying about the decarbonisation hub and bringing regulators, Governments, investors and infrastructure owners—everybody—together, to go down common pathways, using common sets of data and insights.

Q213 **Carol Monaghan:** May I start with Dr Christiansen? You have spoken very passionately this morning about decarbonisation and about consumers leading the charge for that. Is that going to be enough to decarbonise the industry, or does it also need industry-wide commitments and regulations?

Dr Christiansen: I think that is an excellent question. We are seeing enough support from customers to get started, and to start scaling. Again, we are in a segment of shipping where we are blessed with customers who have this very high on the agenda. More than half of our top 200 customers have made zero-carbon commitments, and most of their emissions are in scope 3. We will get a lot of support from them.

There will also be a wide range of customers who will not be interested in paying a premium or whatever, and then you have all the rest of the shipping industry. It is critically important that the regulators and Governments support this in an aligned way, to ensure that we make the right incentives for those who do not voluntarily want to pay a premium, otherwise we are simply not going to make it.

What encourages us is that we see enough demand from our customers to get started and start scaling. We can then start solving the problems as they come along. There is a huge challenge ahead of us, but it is an area where I do not recall anywhere in my career having seen such collaboration and passion from customers, suppliers and regulators. Everybody really wants to solve this problem. That gives us some confidence.

In the way we think about it as a company, we need to solve it for our shareholders and our customers, but we would also like to be seen as providing proof of concept—to show it can be done. There are vessels out there sailing, we are producing the fuels, and others such as the research institute we have founded here in Copenhagen can take that and use it to get others alongside and to put pressure on the regulators and so on. We are quite obsessed with moving fast in this space. We think we can, so that is quite encouraging.

Q214 **Carol Monaghan:** Thank you for the passion and the leadership you are showing in this area.

May I move now to Richard Clegg? Are the UK Government making enough progress on their plans for decarbonising shipping?

Richard Clegg: As the UK we have a key role to play. The decarbonisation hub that I mentioned a moment ago is a key initiative.

I mentioned at the beginning that everybody wants this transition to a low-carbon future. Everybody wants to do the right thing, but the drivers are not there for it—economic, fuel availability, fuel abundance, fuel density. There are no drivers except societal pressure, and the Government are there representing society. What needs to be created is this ecosystem to change. This is all the things we have talked about—the land-based infrastructure, the policy, the regulation, the demonstrators. There is always more to do, but the tipping point will come from Government through policy and regulation.

Q215 **Carol Monaghan:** Do you think that renewable fuel obligations on fuel suppliers in Britain would help?

Richard Clegg: Everybody's situation is different. We covered this a moment ago. Everybody will have different choices and different balances to make. As long as we are all working to the same principle, to decarbonise, that is fine, but to put single obligations and a one-size-fits-all constraint on everybody may not be the right way to go. We need to understand all the pathways that different people in different situations, and different operators and asset owners will go down, and help them go down them. It is about having a basket, a mixture of technologies, and not putting one-size-fits-all obligations on end users.

Q216 **Carol Monaghan:** Finally, you have mentioned a couple of times demonstrator projects. What would that involve? How would that appear to us?

Richard Clegg: There are already demonstrators out there. There are early adopters of technology. Up in Scotland there is a ferry—I think it is called HyDIME—that is running on hydrogen around the Orkneys. The hydrogen is produced from tidal wave and wind energy. These are demonstrators that show the technology feasibility and test the economic readiness and societal readiness for their adoption. What we are talking about with demonstrators are practical, real-world applied examples. The important thing about these demonstrators is to have international partnerships around them. Moving towards international demonstrators is going to help the international co-ordination and adoption.

Q217 **Chair:** Briefly, and finally, to Dr Christiansen from me. I started asking for a bit of a technical explanation of the use of ammonia. You said that the use of hydrogen in its pure form was not compatible with the container ship industry because it could not be stored or bunkered in the required way. You mentioned that container ships refuel once. Does the use of ammonia or methanol solve that problem? Is it comparable in terms of the storage requirements of existing fuels?

Dr Christiansen: It does. Even if you have a spill, ammonia does not pollute the waters because it is an alcohol. There are spaces on a vessel where you can have tanks, but you cannot have tanks on an oil vessel, or an ammonia vessel, for that matter. We are hoping that we can design these vessels without losing any cargo space. We could also reconsider whether we only want to bunker once, and perhaps bunker twice, and make do with smaller tanks.

Ammonia is a bigger challenge because it is a gas and takes up more space on the vessel. We also want to make the vessels dual fuelled. We do not want to end up with these stranded assets in case we cannot get the fuels. In the case of ammonia, we will likely lose cargo space, so we are also considering whether in fact we should bunker twice on a round trip. The vessels are in terminals anyway getting containers on and off.

There are many problems to be solved along the way, but we will take them one by one. We can see the pathway and then we will optimise all the details from now on until the first vessel sets out. We are quite determined that we can make solutions that we can sell to our customers at scale, within years.

Chair: Thank you very much indeed both of you for your evidence today. Lloyd's Register and Maersk are two of the biggest names in shipping, and, as Carol said, the fact that both of you are engaged in thinking about the future is very encouraging. You have certainly helped us with our inquiry. Dr Christiansen and Mr Clegg, thank you very much indeed for your evidence.

Examination of witnesses

Witnesses: Glenn Llewellyn and Dr Yutko.

Chair: We come to our final panel of witnesses. We are going to switch our attention from the seas to the air, and look at aviation. I am very pleased to introduce and welcome our final two witnesses: Glenn Llewellyn, Vice-President, Zero Emission Aircraft, at Airbus, and Dr Brian Yutko, chief engineer for sustainability and future mobility, at Boeing. He is joining us from the USA, where it is quite early in the morning, so thank you for joining us. I am going to start by going to my colleague Carol Monaghan.

Q218 **Carol Monaghan:** The first question is really for both of our witnesses. What role do you see for hydrogen or hydrogen-based fuels such as ammonia in decarbonising aviation

Glenn Llewellyn: Perhaps to set the scene a little bit, already our aircraft are certified to carry on board what are called sustainable aviation fuels. Unfortunately, the amount of sustainable aviation fuel being used across the globe is still at a very small level, much below the capability of aircraft. We need the usage of sustainable aviation fuel to scale. That definitely needs to happen in the 2020 to 2030 timeframe.

Specifically on hydrogen, one of the sustainable aviation fuel types is called biofuel. The other sustainable aviation fuel type that we are interested in in the short term, in the 2020s, is called synthetic fuel or power-to-liquid synthetic fuel, which has hydrogen as its major ingredient. We see synthetic fuel as being extremely scalable, much more scalable potentially than hydrogen in terms of land use, water use and cost. It has much more potential for costs to come down than biofuel. Hydrogen in the context of existing aircraft, and in the context of future long-range aircraft in synthetic fuels, is going to be really important. Compared to many industries, aviation does not have so many choices.

The other way to use hydrogen on aircraft is in its raw form—using hydrogen in its raw state on board the aircraft—and we are pushing that extremely hard. There are definitely challenges and questions that remain to be answered in our drive towards that pathway. None the less, we see it as having extremely high potential.

From all the options we have studied, and we have looked at battery electric and all the different sustainable aviation fuels—butane, propane, methane, ammonia, the list goes on—hydrogen looks like it has the potential to have the lowest climate impact compared to all the other options. On top of that, it has the potential to have one of the best costs compared to all the other options. It is a challenge where we have to develop technology and where the ecosystem needs significant change, but the carrot, or the prize at the end, is significant, and that is why we are pushing so hard in this direction.

Q219 **Carol Monaghan:** May I ask the same question of Brian: what role do you see for hydrogen in aviation for yourselves?

Dr Yutko: We are organised around a four-part pillar, which I would like to describe, and put hydrogen in context for our decarbonisation strategy. The first element of our pillar is fleet renewal and generational efficiency improvements. The second is network and operational optimisation. The third is sustainable aviation fuels. The fourth is advanced technologies such as hydrogen.

Briefly on each of those, on fleet renewal and generational efficiency improvements, new aeroplanes provide significant efficiency gains. Each generation of aircraft reduces fuel use by about 15% to 25%. Fully deploying the latest generation of aircraft is the most significant contribution to emissions avoidance and reduction available to us over the next decade.

Q220 **Carol Monaghan:** How quickly would you renew the fleet?

Dr Yutko: Right now, taking the latest generation of aircraft as an example, between both Boeing and Airbus, there is a minority of the fleet within those market segments. There is a significant opportunity over the coming decade to introduce those new aircraft into the fleet.

Those efficiency gains are important and those efficiency gains absolutely will continue, but we know that efficiency does not necessarily get us all the way towards net zero. The other elements of our strategy come into play.

On network and operational optimisation, we assess that flying aircraft more efficiently in the airspace can reduce emissions by about 12%. These include introducing procedures such as continuous descent approaches, equipment upgrades, GPS, etc. We are demonstrating those right now on a programme that we call ecoDemonstrator, which is a large-scale aircraft that flies and matures these technologies.

The third element of our strategy is sustainable aviation fuels. Given the near-term needs for emission reductions, as Mr Llewellyn pointed out, and the primary sources of aviation emissions being long-haul flights, sustainable aviation fuels offer the most immediate and, far and away, the largest potential to reduce carbon emissions over the next 20 to 30 years in all aviation segments. We have flown 100% SAF on our aircraft in 2018. We have recently committed to making all our aircraft 100% SAF capable by 2030, removing any technical barrier—

Carol Monaghan: Sorry, I am missing that.

Dr Yutko: Sustainable aviation fuels. Right now, just as an example, the aircraft are generally certified to use blends of sustainable aviation fuels that are up to about 50%. Getting to 100% sustainable aviation fuels on regular flights has some technical barriers. We have committed to eliminating those technical barriers by 2030, thus removing any aircraft-level barrier to deploying sustainable aviation fuels at scale. Now we are turning our attention to actually scaling their use in aviation.

The fourth part of our strategy is advanced technology and alternative propulsion systems—electric, hydrogen, etc. We have flown a number of electric aircraft. We have established a joint venture that will certify an electric autonomous aeroplane. That joint venture is called Wisk. It is a small aircraft that carries two people and is fully battery powered.

We have a long experience with hydrogen. In 2008, we flew a fuel cell-based aircraft. In 2012, we flew a liquid hydrogen and combustion-based aircraft. In 2012, we also flew a fuel cell on board one of our large-scale 7 Series aircraft.

Likewise, we have some significant technology development in our space systems that are related. A few weeks ago as part of the SLS programme we had demonstrated a system that has effectively 1 million kilograms of LH2 and millions of pounds of thrust. We are exploring those relevant technologies. We have flown them in the past, and, like Mr Llewellyn, we could talk about the opportunities and challenges there.

Q221 **Carol Monaghan:** Thank you, that was really comprehensive. If I could come back to you again, I understand that Airbus recently halted its research into electric aeroplanes. Do you have reason to believe that hydrogen will be different?

Glenn Llewellyn: To be precise about what we have paused, it is the activity looking at battery-powered aircraft for large commercial aircraft applications. The project you might be thinking about is called E-Fan X, where we were looking at using batteries in a hybrid electric system on board an aircraft. We saw that batteries were not progressing at the speed that we need to achieve the ambitions that we have set ourselves or the expectations from society and regulators. Battery technology is just not moving fast enough for commercial aviation applications.

We have seen in various discussions earlier today that many industries have the option for perhaps short-range missions, smaller aircraft, smaller applications. For very small aircraft, for very short-range applications, batteries are still perhaps interesting. But when we talk about commercial aviation, which is where the bulk of climate impact is, batteries are not an option.

To put it into context a little bit, the best certified lithium ion batteries we could imagine in the coming years are about 150 Wh/kg. That is the amount of energy per kilogram. Hydrogen has about 33,000 Wh/kg. Kerosene has 12,000 Wh/kg. Hydrogen has more energy per kilogram than even kerosene. It has a challenge in terms of volume, which we can talk about, but battery technology would need to go very far to compete with hydrogen for large aircraft applications. That is the bulk of the climate impact and that is what we want to address. That is why we are pushing so hard in our exploration of hydrogen.

Q222 **Carol Monaghan:** We have heard some evidence, and it is limited at the moment, that water vapour emissions can contribute to global warming because they can capture particulate matters. Do we need to be looking at this more carefully?

Glenn Llewellyn: For sure we do. I think the climate science around aviation and emissions at altitude has progressed quite a lot over the past decade, but our understanding, and the level of uncertainty, is still at the level where we need to progress further. We have plans to flight-test various different types of energy, including kerosene, JET A-1, different sustainable aviation fuels and hydrogen. We want to be able to analyse what is in the jet stream behind these aircraft. We want to provide that data to climate scientists so that we can come up with scientifically relevant solutions.

We are already engaged with climate scientists. That is why we have quite a lot of confidence that hydrogen is so promising. Even when you take into account the water vapour, there is no particulate matter and therefore no ice accretion and much less radiative forcing. We see lots of things going in the right direction, but we want to absolutely confirm all that as part of our decision-making process over the next few years.

Q223 **Carol Monaghan:** How dependent are some of the fuels you have mentioned on direct air carbon capture, or other technologies?

Glenn Llewellyn: Synthetic fuel is very dependent on direct air carbon capture if we want it to be carbon neutral. You can use carbon from a point source, so off an industrial chimney, but then you would not be net zero. You need direct air carbon capture in order to be net zero. Therefore, we see it as an extremely important technology for aviation. If we could put that kind of technology on the engine at the back of the aircraft, we would probably do that, but we do not have that luxury. We just could not fly if we did that. That engine is more or less our chimney. We see it as a really good option for keeping that technology on the ground and extracting CO_2 out of the air and in the first stage perhaps sequestering the CO_2, bringing the cost down while we scale the sequestration, and, in a second step, using that carbon for the creation of synthetic fuels. We are going to have to take that sort of approach to get the cost down to the right level for this to scale massively.

Q224 **Carol Monaghan:** Dr Yutko, do you have any comments on these points?

Dr Yutko: I agree with Mr Llewellyn on those points. The non-CO_2 question related to contrails is an area for further study. Both hydrogen and sustainable aviation fuels have potential for contrails. We know that 100% sustainable aviation fuels will have less contrail formation and persistence than jet fuel. There is not yet a strong body of research to compare hydrogen and sustainable aviation fuels, so I think this is a target of opportunity.

Q225 **Carol Monaghan:** My final question is about biofuels. We have been given some evidence suggesting that biofuels may lead to non-sustainable land use, or, if they are adopted in a widespread manner, that there could be insufficient supplies. Do you have any comments to make about biofuels in aviation?

Dr Yutko: Perhaps I could start. There are various feedstock pathways under consideration. We think that they need to be appropriate for the region, and appropriate for the regional norms and economy in which they are produced. Initially, we have focused our attention on waste-based feedstuffs such as municipal solid waste, which has no land use impacts. As it relates to those pathways that may involve crop-based feedstocks, we believe in strong sustainability standards and third-party accreditation on that front. We are not prescribing a fuel that would have land use change. Instead, we are working with various feedstock pathways partners that have both economic potential and the potential to meet third party accreditation.

Q226 **Carol Monaghan:** That is really useful. Glenn, do you have any further comments?

Glenn Llewellyn: Absolutely, we have to be careful about the feedstocks we use and ensure we have properly accredited sustainable aviation fuel. There could be challenges as biofuels scale in terms of availability of feedstock. Using waste is, for sure, the right way for us to go, especially as this moves forward. This potential limitation is why synthetic fuel is so interesting. Synthetic fuel has hydrogen as a main ingredient, and it is why hydrogen in its raw form can be extremely interesting over the long term.

We are advocating an "and, and, and" strategy. Several people have said this. For other industries there is no silver bullet. We are going to need to put maximum efforts into each pathway. Hydrogen certainly looks really promising for multiple applications—synthetic fuel in the shorter term, hydrogen aircraft in the medium term. Biofuel is there now. Let us use it assuming the feedstock is correct, and let us go full speed on all pathways.

Carol Monaghan: Thank you, that is really useful. It is a message we have heard several times this morning, as you say.

Q227 **Zarah Sultana:** My first question is to Glenn. How dependent is Airbus's research into hydrogen planes on the wider uptake of hydrogen in other sectors?

Dr Yutko: That is a good question. It is dependent on hydrogen uptake in other sectors. We need a massive scale-up of renewable energy for global society to meet the Paris agreement. We see many industries needing hydrogen to meet the objectives set out in the Paris agreement. We see the cost of renewable energy coming down. Electricity is a very important driver in hydrogen costs. We see those costs coming down. We see many more end users of hydrogen starting to put their plans in place. That is definitely going to be needed to scale hydrogen infrastructure, to scale renewable infrastructure.

Fossil fuel today is around every corner. That needs to be replaced by something. Our view is that hydrogen may not be around every corner in the future, but it will certainly be around every second corner, because it is such a good energy carrier for renewables. We want to position aviation to benefit from this future ecosystem that we believe is going to be there.

Q228 **Zarah Sultana:** Should there not be a wider uptake in other sectors due to costs or lack of infrastructure or Government funding, how would Airbus intend to achieve net-zero aviation?

Glenn Llewellyn: I think it will be extremely difficult, and it will be extremely difficult for global society to meet the Paris agreement if we end up in that place.

Q229 **Zarah Sultana:** Would you support a sustainable fuel mandate, which some European countries and the EU are talking about?

Dr Yutko: We definitely support incentives to increase the use of sustainable aviation fuels, and, eventually, zero-emission aircraft. The way that this is implemented needs to be done extremely carefully. What can happen is what is called carbon leakage, where people refuel where there is no mandate and then use their aircraft in the locations where there are mandates. Aviation is an international game. We are advocating that places of big influence—and the UK has huge global influence, and the European Union, US—use their global influence to get global measures in place. Where there is a level playing field, and we do not see silly things happening like carbon leakage, I think that is going to be the most productive.

Q230 **Zarah Sultana:** Dr Yutko, do you have any points to make on that?

Dr Yutko: To your first question about the broader hydrogen economy, I think the answer is that it is a prerequisite to see economical use in the aviation industry, if such use were technically possible and, ultimately, certifiable in a product. The reason is that aviation, on the scale of fuel usage in transportation and the wider economy, is a relatively small user, and may not by itself be able to drive the economics of hydrogen to a place where it would be economically viable within this sector. If such aircraft were technically viable and certifiable, ultimately, for them to be economical, it would need a broader hydrogen economy as a prerequisite.

With respect to sustainable aviation fuels, I think the UK Government have been supportive and are a leader on supporting SAF development. We certainly welcome Government involvement in this market, because, ultimately, we have committed to removing the technical barriers to wide-scale use on current and future aircraft. What remains is catalysing the use in the market and the scale economics from deploying widely. We certainly support enabling positive incentives, incentive mechanisms, and working with producers and users to catalyse sustainable aviation fuel use in the aviation sector.

Q231 **Zarah Sultana:** Both panellists have mentioned the role the UK plays internationally. What can the UK do in the UK to accelerate the decarbonisation of the aviation sector? What opportunities does COP 26 present to show leadership in this area? What more can the UK Government be doing, essentially?

Glenn Llewellyn: I think there are several streams. There needs to be a massive increase in the amount of renewable energy available and the amount of sustainable aviation fuel available. This really needs to be done in the energy chain. Whatever can be done there to increase the scale, aviation is going to be a part of the future new energy ecosystem, and we can benefit from that if it scales sufficiently.

On the technology side, it is a question of being clever about how we do this. I will take hydrogen technology as an example. We are taking hydrogen technology from the energy sector and the automotive sector. It is primarily liquid hydrogen tanks, fuel cell technology and liquid hydrogen distribution. We are looking at hybrid systems and electric motors. We may have a small amount of battery. A lot of these technologies are coming from other industries. If we are clever about how we do this, and how we invest, we are going to increase the performance levels of these technologies, because we are obliged to in order to make them commercially viable for aviation applications. That technology should then find itself, in the subsequent phase, back in the energy sector, back in the automotive or ground transportation sector.

The various nations and regions can do something quite powerful there, by recognising the circular effect, and using aviation as a platform to get this higher-performing technology, which will then benefit society more at large. We have been hearing just very recently that, in fact, even for 2021 the ATI research budget for aviation is being challenged, and is going to be reduced compared to what we expected. We are an international company. We need to be thinking about how we keep some of these topics alive, and how we keep them going at the pace that we need.

We are a little perturbed by this, to be quite frank. We are now trying to figure out where we are going to do this research, and how we are going to progress it at the pace we need. With the challenges that we face, we have been talking about needing a doubling of the ATI budget, and, in fact, what we are seeing is reductions compared to what we had set as previous expectations. There is a massive circular benefit and a massive benefit in the UK in terms of these new energy technologies, which I think we have an opportunity to work together on, but in the short term we need to fix some of the challenges that we are facing.

Q232 **Zarah Sultana:** Before I go to Dr Yutko on that, there have been recent announcements—for example, from the South Korean Government—about investing in hydrogen technology. You are an international company. What examples do you have of what other countries are doing on hydrogen research and technology? Is there anything that the UK can learn from that, other than the points you have already made?

Glenn Llewellyn: In Asia, various players are benefiting from Government support, and, in fact, increasing Government support in the current times, in the types of technology we are interested in. We have seen a huge shift in the US with much more investment in the technologies we are interested in. In 2020, we started seeing a very strong position emerging as regards hydrogen strategy, and hydrogen technologies and electrical technologies, in France, Germany, and a little bit latterly in Spain. There are definitely benchmarks and places that are doing this at a very ambitious level. The UK has an amazing powerhouse of technology capability that we would like to benefit from, but this is about technology and economics, and we have to ensure that the two fit for us to take it to the market ultimately.

Q233 **Zarah Sultana:** Does Dr Yutko have anything to add?

Dr Yutko: We think that net zero is a team sport. The 10-point plan is a great model.

Briefly, on what we have done and how we can work together, certainly, we will continue to invest in advanced technologies research and development to improve efficiency, and, ultimately, to decarbonise. Just for a sense of scale, over the past decade and a half we have invested $60 billion into this topic. It would be impossible for either industry or Governments to navigate this challenge alone.

We welcome initiatives like the Jet Zero Council as a significant step in the right direction. That is a forum to work jointly with aviation and aerospace industries on the technologies and policies and regulatory frameworks. Jet Zero is a great model. Boeing is willing to be an enthusiastic participant in the UK Jet Zero Council. I think it would be great and powerful to have both global aviation and manufacturing leaders represented on that council.

I echo Mr Llewellyn’s comments with respect to ATI. We have recently done an accelerator with ATI. I think the work that ATI does is important, and additional focus there is welcome.

Ms Sultana, to your last question about what else the UK can do to prioritise, I think that sustainable aviation fuels offer the most immediate and largest potential to reduce carbon emissions over the next 20 to 30 years in all aviation segments. Initiatives such as the Jet Zero Council and other initiatives that focus on this topic, and help to enable and catalyse scale in that domain, can significantly help to reduce aviation's impact on the environment.

Q234 **Chair:** Thank you very much indeed. A few final follow-up questions from me, perhaps starting with Dr Yutko. In talking about hydrogen, which is the subject of our inquiry, as you know, you mentioned a fuel cell experiment, a prototype in 2008, and you mentioned that in 2012 you deployed hydrogen on an experimental basis on the Boeing 7 Series. That is a decade ago. Can you give me an example of up-to-date testing, or has there been—and this is not a point of criticism—a sluggishness over the last decade on the developmental and experimental use of hydrogen?

Dr Yutko: Thank you for the question. The focus right now is on understanding hydrogen's potential use as part of commercial aviation. There are a few challenges associated with that. Those technology demonstrators that I mentioned, both fuel cell based and combustion based, represent some important technological developments for how we ultimately use those systems in aircraft.

There are a few challenges. Hydrogen needs to be both stored and used on the aircraft in a hydrogen system. It can be stored as a gas or as a liquid. Storing hydrogen as a gas involves very high-pressure composite tanks. Ultimately, when you take the very high energy density that Mr Llewellyn mentioned at the beginning of his comments, and you put that into a container—let us say a gaseous container—and then you wrap the systems around that ultimately to make it safe to be in an aeroplane, the energy density of that total system goes down precipitously.

If you think of a scale of mega joules per kilogram with lithium batteries being roughly 1 MJ/kg, just to give rough numbers, the way to think about a gaseous hydrogen system at the storage level, it is about seven times better than lithium batteries. When you put that gaseous H2 storage system into an aircraft, it can lead it to perform about a two or three times further range than, let us say, an all-electric battery-powered system.

Gaseous H2 storage is a bit like a competitor to a battery-powered aeroplane, which is severely limited in range and capability. That moves you to a liquid hydrogen storage system on board the aircraft. Of course, that imposes challenges related to cryogenic storage. Certainly the energy density of that total system can now be much higher than the gaseous storage system. That liquid hydrogen system comes with other auxiliary concerns related to insulation, distribution, and so on. Liquid storage on board the aircraft is, ultimately, the way to increase the energy density of the hydrogen on the aeroplane. That can be done either by using fuel cells or combustion. We are assessing the ability of those systems to be used at various scales of aircraft and, ultimately, be certifiable at various scales of aircraft, due to some of the inherent technical challenges that introduces.

Q235 **Chair:** Clearly, vehicles in the air, as it were, present more particular challenges than vehicles that run on the ground or on the sea. We have heard in the road sector, and in rail and in shipping, that practical applications are being deployed now. Perhaps it is a little disappointing that the initial work of 10 years ago has not led to something that is closer to viability. Is there a danger that the aviation industry is going to be the one left behind when it comes to either hydrogen or battery technology? I know that before you were at Boeing you were at NASA and you worked on the Space Shuttle. In overcoming what seem to be very difficult challenges, surely the aviation sector should be in the vanguard of this, rather than being seen to be bogged down in the problems.

Dr Yutko: There are inherent physics differences between the various modes of transport. The physics challenges in the aviation sector, and the need for extremely high levels of systems safety, impose some fairly significant technical challenges on actually using and, ultimately, certifying hydrogen aircraft. As an example, the fuel on board the aeroplanes that you fly on today is an inert gas. That ensures that fuel vapour does not build up in the tanks and lead to a problem with electrical systems. Because of this, the storage challenges that I talked about in my past answer, about needing to go from gaseous storage to liquid hydrogen storage on board the aircraft to get to any meaningful scale of passenger transport, that fuel still needs to be inerted. Unfortunately, because of the physics involved in liquid hydrogen, there are very few gases that can inert that system. In fact, helium is the only one. Significant invention is required in order to ensure the safety of the full systems on board to ultimately certify the aircraft.

Q236 **Chair:** I would make a final observation. We have been talking about research and development programmes, and one of the striking features of the industry that you are both in is that between Boeing and Airbus you have a 91% market share. There are many more countries than there are aerospace companies of scale. Is it not rather paradoxical that the research and development should be nationally led when we have two massive global companies? Don't we have an opportunity for these two companies to lead the research and development on this basis, in order to achieve the breakthroughs themselves, rather than turn to national Governments to assist? I will come back to Dr Yutko, but, briefly, Mr Llewellyn.

Glenn Llewellyn: I think it comes back, at least in part, to a point I tried to express earlier. I think we have a circular benefit to society by taking technologies that exist in the energy sector and in the ground transportation sector on hydrogen. Hydrogen is not new. It has been handled and used for decades. Technology has progressed in the last 10 years. We are now going to take that technology and improve it even more for aviation applications. It is of societal benefit if that technology can find its way back into the ground transportation and energy sectors to assist in the subsequent phases of decarbonisation, and in getting to climate neutral.

There is a societal play here if we do things correctly. We have locations across the world that are willing to benefit from this play, from this interaction, from this dynamic. Where there are countries that are not interested in this dynamic, it is more difficult for us to make the investment. We look at two key parameters: the technology and the economics. When those conditions combined are correct, we choose to invest. That is very normal as an approach. The countries that see the circular effect of the technologies will be the countries that position themselves best for the future world, which is decarbonised.

Dr Yutko: I would say that we are certainly not waiting. We are continuing to evaluate the use of these technologies in eventual products as part of our four-part strategy. We believe that there is no panacea in this market space. We will continue to execute that four-part strategy. We welcome collaborating with partners and Governments around the world on this mission.

As I mentioned, we think that this is a team sport. We welcome being part of initiatives led by the UK such as the Jet Zero Council. In fact, we even collaborate with our friends at Airbus on pre-competitive important common problems related to flying aircraft in common airspace, and so on. Aviation is international and extremely co-operative in ways, but we are also not waiting to advance the technologies. We do that as part of our R&D portfolio and will continue to do so.

Chair: Thank you very much indeed for your evidence today, Mr Llewellyn and Dr Yutko. Dr Yutko, we are especially grateful to you for joining us from the United States today.

I am grateful to all of our witnesses for giving us a very thorough and expert and informed analysis of the various challenges in the use of hydrogen in transportation. We will continue our inquiry in a couple of weeks' time.