HOUSE OF COMMONS

Science, Innovation and Technology Committee

Oral evidence: Commercialising quantum technologies, HC 270

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Watch the meeting

Members present: Greg Clark (Chair); Dawn Butler; Chris Clarkson; Tracey Crouch; Dr James Davies; Stephen Metcalfe; Carol Monaghan; Graham Stringer.

Questions 217 - 257

Witnesses

II: Dr Steve Brierley OBE, CEO, Riverlane; Gerald Mullaly, Vice President of Commercial, Oxford Quantum Circuits; Dr Carmen Palacios-Berraquero, CEO, Nu Quantum.

Examination of witnesses

Witnesses: Dr Brierley, Gerald Mullaly and Dr Palacios-Berraquero.

Q217 **Chair:** Joining us remotely from California, where it is around 2.30 am, is Dr Carmen Palacios-Berraquero. Whether you stayed up late or got up early, thank you very much. Dr Palacios-Berraquero is chief executive officer and co-founder of Nu Quantum. We will ask a little about what Nu Quantum does in a second. Dr Palacios-Berraquero was awarded the Jocelyn Bell Burnell medal and prize in 2018 for her work on quantum optics and materials. Thank you very much indeed for joining us.

Joining us in the room, we have Dr Steve Brierley, chief executive officer and founder of Riverlane, a company mentioned a few moments ago. Dr Brierley founded Riverlane in 2016 to develop and build the error-correction stack for quantum computers—areas that we have been talking about. Dr Brierley was previously group leader at the Heilbronn Institute for Mathematical Research and, prior to that, spent 10 years working at GCHQ. Earlier this month, Dr Brierley was awarded an OBE in the new year's honours list for his services to quantum computing.

We also have joining us in the room Mr Gerald Mullaly, vice-president of commercial at Oxford Quantum Computing. Before joining Oxford Quantum Computing, he was director of the Prime Minister's Office and Cabinet Office responsible for leading and scaling government-to-government communications.

We give thanks to all three witnesses.

Dr Palacios-Berraquero, tell us a bit about Nu Quantum, what it does and what progress it is making.

Dr Palacios-Berraquero: It is a pleasure to be here. I am founder and CEO of Nu Quantum. I founded Nu Quantum in September 2018 out of my research at the Cavendish Laboratory, where I took my PhD on quantum optics, as was mentioned.

Nu Quantum is a quantum networking company. We are building the required hardware, which is mostly photonic-based hardware, that will be able to interconnect quantum computers so we can achieve the scales required to address some of the most well-understood and impactful problems we can tackle with quantum computers.

We cannot reach these commercial sizes of quantum computer monolithically in a single quantum computer. We will have to interconnect many nodes together, much like in a high-performance computing or cloud data centre today. We are building that networking layer that will be able to distribute entanglement and create large clusters that are able to work together. That is mostly photonic hardware, but also control and software.

Q218 **Chair:** I ask Dr Brierley to say a bit about Riverlane, what it does and the idea behind it.

Dr Brierley: We solve quantum error correction which is a technology that sits on top of the qubits and corrects errors during computation. Earlier in the session, mention was made of the fact that the big challenge in quantum computing is that the qubit is extremely fragile. We have error rates of around one in 100 in the best quantum computers in the world built by Google or in Hefei in China.

The technology we develop sits on top of the qubits; it takes the data coming out of the quantum computer and processes that very quickly. The reason you need a company to do this is that this is an extremely challenging computational problem. Indeed, the amount of data being generated at scale at a trillion quantum operations will be of the order of 100 terabytes per second. That is the same as Netflix's global streaming. We need to process that data in the same place as the quantum computer.

The only way to solve that problem is to build a dedicated chip, and that is what we have done. This year, we released our first error-correction chip. I have brought with me a copy for you to take a look. This is a classical semiconductor that solves computational problems extremely quickly and is being integrated with quantum computers around the world. We sell this chip to companies that are building quantum computers. Just like Nvidia builds GPUs, which were needed to scale AI applications, so chips for the error-correction stack will be needed to scale quantum computing applications.

Q219 **Chair:** Mr Mullaly, I think I wrongly introduced your company as Oxford Quantum Computing; it is Oxford Quantum Circuits.

Gerald Mullaly: OQC is easier.

Q220 **Chair:** Tell us what OQC does.

Gerald Mullaly: We build quantum computers and make them available to customers as a service. We spun out of the University of Oxford in 2017. In 2018, we were the first commercially available quantum computer here in the UK, and in 2021 the first European quantum compute as a service company. Last year, we had a world first, which was to put the very first quantum computer into a commercial data centre facility. That moves it out of the lab and into the enterprise.

The whole purpose of that is to bring down as much as possible the barriers to access for quantum compute. That means customers from anywhere in the world will be able to access our quantum computer and start to move to real and much more sensitive data and problems. It is built on our core IP. I have a smaller one here, which is the Coaxmon. It is a super-conducting circuit chip that has been redesigned from first principles and with ease, flexibility and scale in mind. One of the big issues is the control wire problem, which is what we are solving through the Coaxmon.

Chair: As you might imagine, we have some more detailed questions,

starting with James Davies and then Chris Clarkson.

Q221 **Dr Davies:** From your perspective, where do you think the UK stands in quantum computing currently?

Gerald Mullaly: I think the UK has done an incredibly good job of building a very vibrant quantum computing ecosystem. Second only to the US, we have more start-ups in quantum computing. We have attracted an enormous amount of private capital—again, only second to the US, which is really impressive.

On that basis, I think we are respected around the world. When we travel around the world and engage with other Governments, but in addition our customers in other countries, being a British quantum computing company is definitely an asset for us.

The next stage is about how we then scale it and move from a vibrant start-up ecosystem to one where we ensure we have unicorns that are global leaders in quantum computing in the future. I think that part of this discussion is the scaling challenge, and what we need to do from a scaling point of view will be key.

Dr Brierley: I completely agree. The first decade of a UK quantum technology programme rightly focused on solving some of the fundamental science questions. Ten years ago, the question was: could you build a qubit at all and, if so, what sort of physics should you be using? That is a big research question. I think the world tried many different ideas and out of that has emerged perhaps five different approaches, all of which look extremely promising.

The benefit of the past 10 years has been essentially a Moore's law scaling in quantum computing, so every 12 to 18 months the quality of the underlying qubits has doubled. That is tremendous progress. The ability to control quantum bits, electrons and photons with that precision is remarkable.

I completely agree with Gerald that the challenge now is to scale this up and create hundreds of trillions of dollars or pounds of economic benefit in the UK and create massive companies here. This is another wave of technology and we should be at the forefront of that.

Q222 **Dr Davies:** Dr Palacios-Berraquero, do you agree with the comments made?

Dr Palacios-Berraquero: I do. Historically, the UK has developed world-class quantum science, and the first quantum programme was successful in turning that into good technology and spin-outs. Today, we have a quantum ecosystem with at least one high-quality company in each part of the quantum computing stack representing each kind of qubit approach. That is remarkable. I agree that the start-ups are respected worldwide.

It is a collaborative, coherent ecosystem; it is managing to bring in end-users as well. Now that we have good science I think that it will continue thanks to the quantum missions. The NQCC retains that coherence for the ecosystem to be able to develop with a clear road map.

Q223 **Dr Davies:** Clearly, there is already much success, but are there areas on which you think the UK Government should focus in quantum computing to build on that success?

Dr Palacios-Berraquero: I agree with what has been said about scale. We need to ensure that these companies are able to be successful, and that will require large amounts of capital, both public and private, so we can play in a global market.

Beyond capital to scale is the ability to bring in capital from abroad and engage with suppliers and customers outside the UK, and for that to be part of the UK's strategy for our start-ups to continue to be top of the list globally.

Q224 **Dr Davies:** Turning to our two witnesses in person, are there any comments they would like to add to that regarding the specific areas of quantum computing on which this country should focus?

Dr Brierley: I think we all agree that the challenge is to scale a great company. How do we do that? I think the answer is quite simple. The Government should buy stuff; it should buy things on the timescale that is relevant to start-ups. There is no point having a five-year procurement process. We will be dead by then. The key thing is for the Government to act as an intelligent customer. We have seen that in many industries being hugely successful.

The semiconductor industry was kickstarted by procurement from NASA. Moore's law was mentioned. On those four data points, 95% of that market was from procurement by NASA for the Apollo programme. The same model would work here in quantum.

There is a huge return on investment for a Government to act as an early customer. There is no point buying quantum computers in five or 10 years' time when they are already commercially available. You will not really be impacting or creating a market.

That is a challenging thing to do. Being an intelligent customer requires expertise on both sides of the discussion, but it is certainly achievable. We are starting to see it already with the APCC's procurement of small test bed systems. I think that is a great idea. These are small.

The next stage needs to be much bigger. That will drive innovation and make it happen in the UK; it will attract companies and talent to the UK, and it will attract capital to the UK. If I can say to my investors, "I've got revenue of £10 million next year"—guess what?—they are much more interested in investing in the company.

Q225 **Dr Davies:** Are there any other state interventions that could be useful?

Gerald Mullaly: Building on Steve's point, it probably breaks down to three areas: access to markets, which Steve covered really well, in terms of the customer and the Government role; access to people, which is the talent side; and access to finance. When we look at finance, from a quantum computing perspective one part is the deep-tech ecosystem, and the stats that come out of the broader ecosystem apply to quantum computing. About 50% of companies do not exist between series A and series B in terms of deep tech. Fifteen per cent. higher survive in the US. Going through six rounds of funding, we are six times less well-funded than companies in the US. When you adjust for GDP, we are less funded than the US, Sweden, China and Israel.

That has a knock-on impact on everything we do from infrastructure, which I think we will come back to as a really important point, to whether we can build our own, but it also means attracting funding from other locations. What we are seeing from other Governments is the development of funds effectively that either direct investment into quantum computing companies at certain series—series B, as an example—or invest in other funds.

Those VCs are the ones investing in the companies. We have done some of that here, but in terms of scale it is probably not what we are seeing in other countries at this point.

Q226 **Dr Davies:** Dr Brierley, I am going to repeat a quote from you regarding quantum computers that "the short-term hype is a bit high, but the long-term hype is nowhere near enough". Why is that the case?

Dr Brierley: The quantum computers we have currently are not as good as your laptop or mobile phone because errors overwhelm the computation. We have not yet built the scale of the quantum computer needed and included quantum error correction. If people are talking about having a quantum advantage today, they are over-hyping the technology.

Where we are underestimating the impact of quantum computing is in the transformational nature of this new type of computer. For me, that really means the ability to simulate perfectly molecules and electrons, the physics of the very small. This has a transformational capability across multiple different sectors.

In an industry such as aerospace we have two things: equations that tell us what will happen in the system, and computers that can solve those equations. With these two ingredients, the sector designs aeroplanes. It does not discover flight; it does not discover the next generation. It uses computers for design, whereas in areas such as pharmaceuticals, drug discovery, materials design or the search for a new catalyst for, say, carbon capture or some other industrial process, we have the equations of motion. These are called quantum mechanics, which are now 100

years old, but we still do not have the computers that can solve those equations. That is why we still talk about drug discovery and the discovery of a new material or industrial process.

The potential of quantum computing is radically to change how those entire sectors develop new products. That is why I believe this will be a hugely transformational technology. Understanding how that change in whole sectors and things are developed is hard to comprehend at this point.

Dr Davies: That is very exciting.

Q227 **Chris Clarkson:** Dr Brierley, what support did your company receive from the Government and other sources to establish scale-up and develop your quantum business? You mentioned that you would like to see the Government spend a bit more on this. I am interested to see what is actually there for a company like yours stepping up.

Dr Brierley: The industrial challenge strategy fund in quantum computing was absolutely brilliant. It set out some clear goals and things that the programme wanted to see. We were part of that and led several consortia that developed some of the early technology. For example, we brought together all the companies building different types of qubit into a single consortium and looked at the common problems at the software layer.

I remember that three or four years ago the interview panel asked the consortium questions like, "How much new capital can you bring to the table?" Between us, we were a bunch of start-ups at a very early stage. We had the goal of trying to solve some of the software problems in quantum, but I think most of the companies were there because they wanted to build new companies.

We had the goal of raising £60 million at that point. It seemed pretty outrageous to say that to the review panel. This was a £6 million programme. In the end, the consortia raised over £150 million in additional capital.

Those sorts of programmes have been hugely successful in allowing people to get started—certainly allowing us to get started—to demonstrate and de-risk some of the earlier-stage developments, and then use that as proof points to continue to grow.

Q228 **Chris Clarkson:** In your opinion, when the Government make interventions is it more a case of removing some of that risk in the initial investment and being able to try new and innovative things, or is there some specific thing on which you would like to see the Government spend more time and investment?

Dr Brierley: That is a good question. It has been very much around solving very specific technical problems; it is the next step in the road map.

Where is that going? As part of the programme, the goal of getting to a trillion quantum operations is exactly the right one. The first big milestone is a million quantum operations by 2028. That is an exciting milestone; it will be a huge inflection point for the industry globally, but we need to get on with building that.

Scaling up quantum computers from tens and hundreds of qubits to thousands of qubits is the next big challenge. Integrating error correction at that scale has also not been done.

These are the sorts of programmes I would love to see as part of the next phase.

Q229 **Chris Clarkson:** I was struck by something you said earlier. You said that companies in the States are 15% more likely to survive that initial funding stage. What are the obstacles in getting capital in both series A and series B funding? I put that to all panellists because obviously you all have experience of it in one form or another.

Gerald Mullaly: We are going through a series B at the moment and we had our first close just before Christmas. We have noted probably a couple of things. There is a risk appetite in terms of VCs about taking these sorts of bets on emerging technology. You tend to see differing risk appetite in other regions. We have had a very strong engagement from APAC as an example in terms of investors from that region.

The other side—this is similar for all customers—is the process of learning about quantum and ensuring you can better take that risk with respect to a new technology area.

That will be a growth process overall, but there is something about pricing the risk. We know from our direct engagements with VCs in the European region and the UK that they tend to look towards the US in particular—I do not know whether your experience has been the same—to price the risk. On that basis, we tend to see lead investors coming from other locations.

We look at the composition in our round. We are very appreciative of the support we have received, including British patient capital overall, but the bigger investors and larger ticket sizes tend to come from other regions. That will be key as we scale and ensure we are able to reach some of the milestones and some of the very exciting missions laid out by Government. It will require capital.

Q230 **Chris Clarkson:** Dr Brierley, I would be interested to see what is happening in the US rather than in our market.

Dr Brierley: I think that is a good summary. It is really about risk appetite and what sort of companies we want to build.

The US is a market with a large number of investors who are really interested in building companies with $10 million, $100 million or $1

billion cap. You do not see as many of those in the UK. As a result, there is a much more lively ecosystem of investors willing to take these kinds of big risks. Either this will be huge or nothing, but that is the kind of portfolio they are trying to build.

Q231 **Chris Clarkson:** Dr Palacios-Berraquero, do you have any thoughts?

Dr Palacios-Berraquero: I add that the risk is the size of funds. Among the people giving evidence today, we probably have on our table pretty much all the UK deep-tech investors. Very few of them—maybe none—have funds large enough to support our next stage of growth. Most quantum start-ups in the UK have raised less than £10 million, so it is seed rounds. A few of us have raised more than £10 million. The largest was raised by OQC, and there have been a few £40 to £50 million per round. For at least 10 to 20 start-ups to be successful and continue to scale we will need 10 to 20 times that: £50 million to £100 million investment in the next two years, and more in the next five years. The next few years are really important to get us through.

A good number of funds in the UK invest in deep tech and hardware, but none of them is large enough. There are a few ways. One way would be to have larger deep-tech funds, and Government can influence that and help with incentives and funds.

We can incentivise funds that are larger but are not deep tech and will not be so accustomed to investing in hardware, for example to invest in quantum start-up, and Government can play a role there—I will get on to that in a second—or we can incentivise capital coming from elsewhere into the UK.

Recently, a report was carried out on investment appetite in the UK and a few recommendations to Government came out of that. They have a high impact score for those who want to invest in quantum. That is Government as a customer, Government being an LP in funds—a long-term commitment from Government to quantum technologies and incentivising market pull.

Q232 **Dawn Butler:** Listening today, maybe the Government's Advanced Research and Invention Agency should be investing in this kind of research. Maybe as a Committee we will take that back and see whether this is one of the areas Government are looking to invest in. How closely connected are you all? Is this the first time you are all meeting, or have you met before?

Dr Brierley: It is a very friendly and vibrant ecosystem. We all work together on various different projects.

Q233 **Dawn Butler:** You all share information, so there is that technology transfer within that ecosystem, which is reassuring.

Dr Brierley: Yes. What we are really talking about here is aligning road maps. We are all pursuing different parts of the stack. As Carmen said,

one of the things that has emerged over the past 10 years in quantum computing is the maturity of the ecosystem. Five years ago, the only way to build a quantum computer was to build everything yourself. You needed to be the Intel, the IBM, the Microsoft, the AWS and the Google of quantum. A company famously said that.

As the technology scales up and the ecosystem matures, you can start to see parts of the stack that are very hard and require specialisation. This is one of the trends that has been consistent over the past five years or so, and it is where the UK is strong because it has strength at various different parts of the stack. It gives the UK the opportunity to win in one part of the quantum computing stack. That is probably a reasonable expectation.

In the semiconductor industry, no one country owns the entire supply chain. I do not think we should expect that to happen in quantum computing, either.

Q234 **Dawn Butler:** Yes, a bit like the world wide web.

Dr Palacios-Berraquero: The industry in the UK is now at the point of maturity that we have recently created an industry group. The effort towards that started about three years ago. A group of us in the quantum industry came together to plan how we would launch what is now UKQuantum. We were encouraged by Government to be a single voice of the quantum industry to Government, and that has been useful in liaising with Government to build the quantum strategy. That has now been formed. We have over 50 members and growing. It is a sign of an ecosystem that is maturing and collaborating in a productive way.

Q235 **Dawn Butler:** Has anybody flown the coop? Has anybody left the UK and gone elsewhere because there was more money and more investment?

Chair: Dr Palacios-Berraquero is speaking from California. I hope that is not an ominous sign.

Dawn Butler: Besides you, Dr Carmen.

Chair: She is coming back, I hope.

Dr Palacios-Berraquero: PsiQuantum was the first case of this. I do not know whether that would happen again now; it was quite early in the formation of the quantum industry. Professors and researchers from Bristol University who had developed technology to do photonic quantum computing went to Silicon Valley to start PsiQuantum. It is one of the companies that has raised the most capital in the whole global quantum ecosystem. Recently, it has returned at least part of its activity to the UK. That was very early on, I think 2016 or 2017, when there were not very many quantum start-ups in the UK or anywhere in the world, so the structure of support and potential for growth in the UK was not so evident. I do not think that that has happened again, but maybe my colleagues can confirm.

Gerald Mullaly: PsiQuantum has raised well over $650 million. We collectively would be nowhere near that. That is the challenge for us. PsiQuantum solved the need from a funding point of view. It went to the US early and raised well over $650 million. There is always that constant challenge on our side: should we? Ultimately, we need to access that sort of capital over the longer term. That is just building on what Carmen said.

Q236 **Dawn Butler:** Thank you. Are you all still friends, though?

Gerald Mullaly: Yes. It could be a good way of understanding the science. I am going to murder the science here. We build superconducting circuits and quantum computers, but we generate errors. We would work to Steve to mitigate and correct those errors. We in the future will need to connect up our quantum computers, and that is where we would work with Carmen. That is a simple "Janet and John" way of explaining it.

Dawn Butler: That is good. I wondered about the parallel testing of how this system works. Brilliant. Thank you.

Q237 **Stephen Metcalfe:** I suppose as all new technologies mature and develop they present the potential to be misused. They present a risk, whether intentional or unintentional. What work is being done to ensure that responsible research and innovation is being conducted, the idea being just because you can do something does not mean you should? How is that message being shared and propagated?

Dr Palacios-Berraquero: I can share a few recent developments. The National Quantum Computing Centre alongside UKQuantum, the quantum industry group that I just mentioned, has recently launched a work programme around responsible innovation in quantum. The fact that there is both national Government involvement from the National Quantum Computing Centre and engagement from industry is encouraging. That is quite recent, but that bodes well for developing good policy and good ethical frameworks for quantum, which will be critical. We still have time to do that if we take it seriously from now.

Dr Brierley: You are absolutely right that this is a dual-use technology. It is incumbent on us, companies and Governments and other participants, in the ecosystem to ensure that it is used responsibly. As Carmen said, the responsible quantum taskforce is great. There is a lot that we can learn from AI because, to some extent, that is a technology that is ahead of quantum and perhaps missed some of the opportunities to ensure that it was used responsibly early. Those learnings are great and they should be applied across for quantum computing.

Q238 **Stephen Metcalfe:** Okay, great. Gerald, do you want to add to that?

Gerald Mullaly: Yes, just to build on Steve's point, the learning from AI will be critical. The principles developed in AI such as safety, security, transparency, fairness, responsibility and contestability are all interesting

principles for us as an industry to explore. The more we can lay down those principles as a community, the more it is built on the foundations, which mean that in the future it is less likely to move in the directions that you mentioned.

The other thing to say is that there is a strong understanding in the community about the risks from a national security point of view, and on that basis very alive to approaches in various domains or hostile states in terms of the activity.

The area where we would probably look to do more is what risks there are from quantum computers from a hostile state on an ongoing basis, and the more that we can research and see the threats that might attack a quantum computer and then interfere with a quantum computer, the more we will be able to protect against it in the future. The knock-on benefit of that is that we are also educating the community about those risks.

Q239 **Stephen Metcalfe:** You touched on national security risks. If we fail to research and innovate responsibly, what other risks are there? Are there any risks that are less deliberate? National security would be a deliberate attack or attempt to attack. That is a risk. Are there any unforeseen risks? No? Okay, well, that is good. No unforeseen risks. You heard it here.

You compared quantum with AI and some of the work coming. We are doing an inquiry into AI at the moment, and one of the themes is always accountability and transparency. Do we need to be concerned about that with quantum computing? What can be done to ensure that those issues are addressed?

Dr Brierley: The first thing to say is that we do not even get to decide if we do not win. If the UK does not play a leading role in the development of the technology, we will have no voice in how the technology is used. If you look back at the development of the semiconductor industry, what would the world be like if the west did not win the race to build semiconductors? It would be very different.

The important thing is to be leading the innovation, to be building leading companies and to have leading research organisations so that we can influence these decisions.

The governance structures around the National Quantum Computing Centre all look very promising. They are in the early stages, so they need to continue to be built out.

Gerald Mullaly: Steve has covered it really well, and it is an important point. If we are going to set that global framework, we must ensure that we are leading, and that will require leading institutions from the UK, whether research or national.

In addition, it will be very hard for us to set that global framework if we do not have globally leading companies. That is going to be the absolute core to ensuring that the framework and the values that underpin that framework globally are British, or at the very least are very much aligned to British and ally values.

Q240 **Stephen Metcalfe:** Carmen, do you have anything to add?

Dr Palacios-Berraquero: I have a couple of things. I have a slightly different approach on the accountability and transparency. There is some work being done and led by Professor Elham Kashefi, the CSO of the National Quantum Computing Centre, on things like verification—being able to say, "This computation was done by a quantum computer and it is correct." That aspect of quantum computing will be important as it gets more commercial and still needs to be much more developed.

I go back to the unforeseen risks. There is a big risk that we might face, not so much in the use or misuse of quantum computing but on the supply chain. I am sure we will talk about supply chains more, but we need to pay attention to each part of the supply chain and how it will develop and how vulnerable we are as companies to risks elsewhere in our supply chains.

Q241 **Tracey Crouch:** This is a slight recast of the question that has just been asked. Steve, your response to my colleague's question about accountability and transparency was excellent and explained the thought. I want to press on what role you think the UK Government can and should play in developing global standards and regulations. Professor O'Brien referred to it as "good governance". I hear what you say—we have to be in it—but what should the Government be doing?

Dr Brierley: Connecting with counterparties in countries that share our values is probably the most important thing. International standards bodies are starting to think about quantum computing. It is absolutely vital that we are part of that conversation with our allies. Those standards in other sectors such as telecoms have become extremely important. It is very early to say, "The correct protocol for these two components should be this." I think we are not there yet. As we get to that point, being involved in those international standards organisations and on those committees with our allies and sharing the information at appropriate levels will be critical.

Q242 **Tracey Crouch:** Are we? Are the UK Government on those committees?

Dr Brierley: Some of them, yes. There are definitely some where there is a much larger number of Chinese participants, so not uniformly.

Q243 **Tracey Crouch:** Are there any particular ones that you think that we should be on? We have the opportunity as this Committee to make recommendations to Government, and if the industry is thinking that we ought to be more involved in some areas of development about regulation and guidance please let us know.

Dr Brierley: It is an important balancing act to play. If you go in too heavy and say, "Hey, there should be a tonne of standards," that is the wrong approach because the industry is still new. In the UK, it is led by NPL, which is the standards body. It is very good at nudging companies to say, "Hey, guys, there's a committee. Do you want to be part of that?" Of course, that competes with other priorities. The truth is people do not always engage in that.

The other challenge is in export controls. Carmen already mentioned supply chains. I can see why we have tight export controls with some countries, but we also have export controls between the UK and the US, and that does not make any sense in a technology where we are working together. It is not just possible—perhaps it is a bit beyond my pay grade to be able to say how to do that—but lowering those barriers with like-minded countries on technology such as quantum while maintaining them with other countries that we are not so keen to work with is the way to go.

Q244 **Tracey Crouch:** We are definitely coming on to supply chains, but, Carmen, may I just ask you about the development of global standards and regulations? Are you feeding, with your expertise, into any development of standards and regulations?

Dr Palacios-Berraquero: I will echo what Steve said, which is that it is still early for most of these standards to be developed, certainly on quantum computing and on quantum networking. Perhaps we can highlight two standards efforts. One is to do with the quantum key distribution—secure quantum communications. I believe there is good UK representation, but I am afraid I do not know what the proportion of UK players is on those.

It is also worth mentioning post-quantum cryptography, the development of new quantum-safe cryptographic codes. One of the main threats of quantum computing is that we will be able to decrypt most public encryption, so we need to develop new ways of encrypting information—different algorithms. In the US, I believe NIST has launched a competition with different codes being proposed. Some of them failed very quickly. Some of them are still running. It is important for the UK to get more involved with the development of that post-quantum encryption.

Q245 **Carol Monaghan:** The national quantum strategy says that 85% of quantum companies are currently importing elements. We have had evidence, both written evidence and evidence this morning, about the lack of strategic investment and the need for greater investment in quantum manufacturing. Carmen, what areas of the supply chain do you think need development to ensure that we have a successful quantum infrastructure?

Dr Palacios-Berraquero: I will talk about the areas where we need to source things from abroad and where we see the most risk. One is in

particular kinds of lasers—very high-performance lasers—but that perhaps is less risky because we have a good industry in the UK.

The second one is advanced optics, which we mostly source from Germany.

The last one, and perhaps the most critical, is integrated photonics. We work with a company in the US and a company in Taiwan to develop our quantum integrated photonic circuits. The development of photonic circuits will be critical to our ability to scale quantum systems, and currently there is no scaled up infrastructure in the UK to address that.

Q246 **Carol Monaghan:** Carmen, is it necessary to have that in the UK? If we are able to source these things from Europe and Taiwan, why do we need to have it in the UK?

Dr Palacios-Berraquero: It is a good question. There are few suppliers in the world for the development of advanced integrated photonic technology. That adds to the level of risk and it decreases the control that we have over that part of the supply chain and our ability to accelerate our R&D towards production.

Q247 **Carol Monaghan:** Would either of the other two witnesses like to add to that?

Gerald Mullaly: In terms of OQC, about 80% of our supply chain is British, which is a really good indication of the ecosystem from a components point of view. Within that 20%, there are definite risks.

To build on Carmen's point, it tends to break down into single or a small number of suppliers, so you have concentrated risk. Another risk area has more to do with performance. Some of the components are manufactured for other industries and are being sold into quantum, so they are either below spec or not quite right for what we require.

The last one, a smaller one, is that currently some of the suppliers are in certain countries that we know we cannot engage with. They are some of the risk areas.

If I was going to pull out something related to your important point on infrastructure, some of the highest-risk components are underpinned by fabrication and by fabrication facilities that are higher spec in other countries. At this point in time, for us certainly in superconducting circuits, we utilise university-grade fabrication facilities, which is great for that first phase of pre-seed, seed to series A, but when you move into the scaling you need commercial grade, and that is a much higher-spec cleanroom facility. There is an interesting parallel between what we require from a QPU perspective and what components manufacturers require in addition. That fabrication side is critical.

We have seen approaches by other Governments for us to build manufacturing facilities in other countries. One of the professors earlier

said that an advanced manufacturing facility for quantum in the UK would be a great idea. It is definitely already on the minds of other Governments.

Q248 **Carol Monaghan:** Are there people within the industry who are having these discussions with Government about the need for this?

Gerald Mullaly: Yes. Carmen mentioned earlier UKQuantum, which is the industry group that has formed, and Carmen is playing a leading role to ensure that all of that is fed through to Government. As we know, there is a review ongoing at the moment with respect to infrastructure needs. It probably comes back to Steve's earlier point about pace. We cannot wait three years because we would fall so far behind over that three-year period. We need to move as fast as possible.

Q249 **Carol Monaghan:** Three years is short in Government terms.

Gerald Mullaly: It is, but it is a long time in quantum.

Q250 **Carol Monaghan:** Do you have any idea what we are talking about money-wise?

Gerald Mullaly: I will not put a figure on it, but we can feed through maybe through UKQuantum. To be fair—and it is to Carmen's point earlier as well—there will be specificity according to certain modalities about what is required. As part of our work, it would be good as an industry to feed through in totality what different aspects of infrastructure are required, and then hopefully identify the ones that are common across the different modalities so that we know from a Government perspective there might be a sweet spot for the industry.

We are not so much asking Government to build the whole thing. It is much more that there is a capital side that we could de-risk a bit, and then using industry we can invest the funding that we receive from investors. You have Government and industry collaborating for the good of everyone in the ecosystem, not just individual companies.

Q251 **Carol Monaghan:** Yes, but it has to be done yesterday.

Gerald Mullaly: Ideally.

Q252 **Carol Monaghan:** Steve, do you have anything to add?

Dr Brierley: Riverlane is, essentially, a classical semiconductor company. Our supply chain is entirely established and there is not much the Government are going to do about that. That is by design. We use fabrication facilities. We have partners around the world that are, essentially, building the same technology for other sectors like the automotive sector.

Q253 **Carol Monaghan:** What are your biggest suppliers?

Dr Brierley: We use fab in the US and Belgium. It is the traditional semiconductor supply chain. The reason we are in the UK and not in

Silicon Valley is not just capital; it is the people who are already here. The skills we need are chip design expertise, and that is what we find in abundance in Cambridge.

Finally, I do not think the UK needs to build everything. We should be looking globally at who else is building what in this supply chain and pick a small number of things to be world-leading on, and then get the rest from everyone else.

Q254 **Carol Monaghan:** Are there any facilities within the UK already that could be adapted or expanded in order to do this?

Gerald Mullaly: Yes, definitely. There are a number of good fabrication facilities but just not at the spec, and that could be something in terms of upgrades rather than greenfield builds.

Chair: Finally, Stephen Metcalfe will pick up on something that has already come up in terms of export controls.

Q255 **Stephen Metcalfe:** Yes, I just wanted to ask for your experiences. Where you have been exporting goods or services, how have you found it? Assuming you have undertaken that, has it been an easy process or a difficult process? How would you like to see the process improved? This is your opportunity to lobby the Government through our report.

Gerald Mullaly: I will start on that one. We have successfully sold a quantum computer to Spain. It was a challenging process. We have expanded to Japan, and that means we need to export in addition to Japan.

To pick up a point that was made earlier, this might be something we could do more to have quantum bridges or to have certain specific agreements with Governments that are allied or very close to us such as AUKUS. We mentioned the US earlier. That would be very helpful for us. It would mean that we would probably be incentivised to move towards certain countries, but that may not be a bad thing over time. Certainly, from an AUKUS quantum computing capability, broader across those three Governments, that might be something that would be a very good thing. Support and help with streamlining efficiency on export controls is important, but certain countries are more important than others.

Q256 **Stephen Metcalfe:** Before I go to Steve and then finally to Carmen, you said it was a challenge exporting to Spain. What was the specific challenge? Was it the lack of understanding from the regulators?

Gerald Mullaly: It tends to boil down to, maybe not surprisingly, dual-use. It is usually the case that the countries that we are exporting to have certain regulations in place around dual-use. Ultimately, there is the question of the whole quantum computer versus certain parts of the quantum computer and what is dual-use within that context. That took quite a long time to work through.

That is where it fits with the AUKUS quantum bridge-type approach. It is within that national security and defence regime where you tend to have the issue. If we can do something about that with allied Governments, we would be able then to ensure that there is a faster process for export to those countries at the very least.

Dr Brierley: I would echo what Gerald said. We sell primarily in the US. We effectively have an almost separate supply chain on the US side so that we can build the product over there. That is because, as Gerald said, the components have dual-use, so there are export restrictions between the UK and the US. I would love to see something around that kind of quantum bridge.

Q257 **Stephen Metcalfe:** Carmen—not necessarily exporting from the UK but perhaps from the US.

Dr Palacios-Berraquero: I would echo what has been said. Export control is going to be a big challenge for the industry and one that could have bad consequences in slowing us down and one where the Government can help.

The thing that I would ask for from the Government is clarity. As we start to try to understand what challenges we might face in export control, we are finding it hard to understand and even find the lawyers and the people who know exactly what we might face. As a first step, clarity and then bridges to certain countries will be critical if we want to be a global player.

Chair: That concludes our evidence this morning. I thank all our witnesses, in particular Dr Palacios-Berraquero? I hope she will have a good night's sleep after this. It is rather late at 3.30 in the morning, but we are very grateful for your evidence.

We are very grateful to Mr Mullaly and Dr Brierley for coming in person, as with all of our witnesses today. We have been lucky to have some PhD students from Imperial College observing proceedings. They have helped with some of the written evidence that Imperial gave, so we are grateful to them, too.