S03E06: From space science to quantum computing: A conversation with the DLR Quantum Computing Initiative

Dr. Robert Axmann (00:02):

We have a certain set of algorithms, so mathematically-defined problems where quantum computing has the potential to be much faster than classical machines. Now, we have to prove that we really can, in real-world problems, outperform HPC systems and this requires error-corrected hardware.

Kyle Fox (00:17):

This is the Smarter World Podcast focusing on breakthrough technologies that make our connected world better, safer, and more secure. I'm host, Kyle Fox. Each episode, we introduce bright minds and their approach to a more sustainable world. We discuss the opportunities and challenges they face and how technology can change the world for the better. Today, we're talking about a technology that when brought into application will fundamentally change the world we live in. It can process data significantly faster than classical computers, allowing it to solve complex problems that can help society in many ways, including weather and climate model calculations, accelerated development of medications and vaccines, improved model calculations for mobility and logistics, cybersecurity protection, and many, many more. The technology I'm talking about is called quantum computing. We are joined today by Dr. Robert Axmann, head of German Aerospace Center's DLR Quantum Computing Initiative to talk about the organization and its latest milestones. Just recently, NXP, eleQtron, and ParityQC working together with the QC Consortium of the DLR Quantum Computing Initiative revealed the first full-stack, ion-trap based quantum computer demonstrator made entirely in Germany. Welcome, Robert.

Dr. Robert Axmann (01:50):

Thank you very much, Kyle. Thanks for having me.

Kyle Fox (01:52):

You've had an amazing career. Let me mention a few things for our listeners, a PhD in aerospace engineering, you have worked on satellite missions, the ISS, and now head the DLR Quantum Computing Initiative. So basically, you're an actual rocket scientist. So could you tell our listeners a little bit about yourself and how you arrived at and what you do at the DLR?

Dr. Robert Axmann (02:12):

So my background is mechanical engineering. I studied at the Technical University of Munich. Mechanical engineering was a specialization in aeronautics and finally, I ended up with a very specific focus in the area of rocket science, so space science actually. And once I finished it in England, my diploma at that point in time, I came back to Germany and thought about what's next, so what's to be done after university? And I decided to go and start my career at DLR which is, it's similar to the American NASA, of course. So we are doing all the rocket science stuff. We are doing the aeronautics research, we are doing mobility research within DLR. We are working together with industry and with fundamental science to do the transfer between the fundamental science and the industry, so to develop applications within DLR.

(03:06):

And I think it's very interesting to work for DLR. So I started there my PhD specializing in satellite operations optimization, and once I finished that, I had the pleasure to head two missions, two scientific satellite missions within DLR. And after nearly a decade of doing this, I switched my position and I started working for the board because I did a lot of engineering project work up to that time and have been asked if I can work for the board. And I decided, okay, yeah, might be a good chance to have new insights in what's the reason that missions come or even that they are canceled, how do we approach new technologies? What is our strategy, for example, for any kind of research in the area of climate modeling?

(03:52):

And after then, heading a new institute that has been founded in 2017 as a founding director, a job which I did close to three years, more than three years. I expected initially it'll be just one year, but it took longer than expected to find the first real director, not the founding director like me, but the real director. So I did it until 2020. And in 2020, we started with a discussion in Germany, what are we doing with quantum technology? And the government also discussed what's the next step in quantum technology, and we developed a new project so that's what we call QCI, the Quantum Computing Initiative in 2020.

Kyle Fox (04:29):

You are four years into this initiative as we stand today.

Dr. Robert Axmann (04:31):

Yeah, actually since summer 2020. The first discussions started in summer 2020. You remember at that time, we had the pandemic. We had a lot of fear above the economy, and in Germany we had the initiative of the government to give new fresh money into different subjects, relevant subjects for the future and quantum technologies overall and quantum computing specially has been one of the focus points for this initiative. And 2 billion euro-

Kyle Fox (05:03):

Wow!

Dr. Robert Axmann (05:03):

... has been invested at that point in time and we have been getting within the last 740 million euro at that point in time. And that was our basis to build a new concept of the QCI. So how can we develop the entire ecosystem within Germany, within Europe concerning quantum computing together with industry with startups. That's basically what I did then since 2020. So development of the concept and then building up a team within DLR because we didn't do a similar initiative in the past, never, ever before. So it's the first time for us to have such an initiative. We operate satellite fleets like the Galileo navigation, constellation, but we didn't build an ecosystem up to now. So now, it's 2024 and we have the first quantum computers built and paid within this initiative already for ministry within DLR.

Kyle Fox (05:53):

When I think about it's four years, it seems like such a short time to be able to produce a working system because you were talking about building the team. From my uneducated view, it seemed like there's probably not a lot of college courses that are pumping out people that understand how to work in a quantum environment. So building up a team, you're very much so still at the forefront of what's happening in the industry even though there's a lot of press, there's a lot of discussions about quantum computers. The fact that y'all went from an initiative to hardware in four years seems remarkably fast and huge kudos to your team to be able to pull that off.

(06:24):

So as you said, there's a lot to unpack with everything that you discussed. So let's start with some of the basics. So I'm a space super fan and I loved how you said instead of rocket scientists, space scientists, I totally agree with that and I've been anxious to see the first quantum computers start working since first reading about their potential in sci-fi books at a young age. So let's help our audience out with some fundamentals on quantum computing.

(06:47):

So we mentioned that quantum computers have the potential to change the world we live in. So the big question is how do they do that? My understanding is DLR focuses on ion trap as the primary approach to quantum computing with the hardware you've made. Unpack that a little bit for us. What makes that different from other approaches? Why did you choose that and what do you see some of the basics moving forward?

Dr. Robert Axmann (07:06):

Yeah, we are not just focusing on ion-trapped quantum computing technology, but nevertheless, it's of course one of our big focus, let me put it this way. We thought about at the beginning of the initiative what technologies to build quantum computers to build qubits might be worth trying to be developed within our initiative. And we discussed a lot internally where a lot of market research within QCI. So my team is management team operating laser labs and clean rooms and also doing the project management on our contract side. But our initial focus was to understand what's the market offering in 2021 when we started with our contracting. And we found that in the area of superconducting quantum computing, we had a lot of activity already, especially in North America.

(07:54):

The North American companies are very active in this area, superconducting quantum computing qubits. So we had a look at also other technologies like ion traps for example, but also neutral atoms, NV centers, photonic quantum computing. And we decided, okay, we found that in Europe we have a very active startup market also with the ion trapped quantum computing technology. And this made the decision that we are willing to contract several projects in the area of ion trapped quantum computing.

(08:24):

And one of the advances of ion trapped quantum computing, they're very stable. So ions are uniform, they are not manmade objects like a super thing which are manufactured individually, but one ion is another one. So you don't have any production errors within the system. They're very stable, they have long coherence times and they're easily to handle also at not as cool temperatures like the superconducting systems, so they need not that much cooling. So it's some of the advances of ion trapped quantum computing technology.

Kyle Fox (08:56):

I hadn't realized that just from the manufacturing of it, it would be easier because ions are ions, you're not having to manufacture something. I guess you could say that nature actually provides it for you. And we hear a lot about error correction and stability of qubits as challenges to getting a production grade ready to go on a computer. And we're going to unpack a little bit about use cases next, but is there anything about the approaches you're looking at that you've seen challenges in terms of scaling this up from your approach or are you still in the research phase to figure out what's the best fit here?

Dr. Robert Axmann (09:27):

For us, the point is we have contracts for the different startups or SME companies building the quantum computers the fast, and we closely monitor those projects and we see that they all have their challenges and also ion traps do have their challenges. So I'm really curious to see how the different qubit technologies are approaching the set goals. So within the initiative we have quantum computers of up to 100 qubits. So neutral atoms was 100 qubits, 50 qubits was ion traps for example. And what we have up to now, 4 qubit prototypes and in the future we expect the next steps are 10 qubit prototypes and we are step by step from 4 to 8 to 10 to let me say 20, 25, 50, 100 qubits that are the next steps that we are expecting out of our contracts concerning the prototypes to be delivered.

Kyle Fox (10:16):

Thanks for the introduction on the approach there for quantum computing. And I know a lot of people want to know what is it going to be useful for? And there's certain things that out in the press they'll talk about, about things around big data, that sort of thing. And I want to impact that in two stages here. Maybe talk a little bit about and help us understand what makes a problem lean more to a quantum solution versus a classical solution or is it even able to describe it that way? Are all problems capable of being solved with a quantum computer? Is there a certain class that you would want to focus on?

Dr. Robert Axmann (10:49):

I think it's the other way around. There are maybe some problems that can be solved on quantum computers much faster than on classical machines, honestly. So we do from theory already know several sets of problems that can be modeled and solved on a quantum computer very fast, so exponentially faster than on classical machines. But usually, you have an overhead, you have also the little problems that occur if you're going to program an algorithm. So it's not yet clear if we are really coming to a quantum advantage at the moment, we are pretty much sure and also we see that we see, so venture capital is pretty much sure that there will be the quantum advantage in the future. But starting at the basics in '94 with the Shor's algorithm, it has been proven for the first time from theory that quantum computers can solve certain problems much faster than classical computers.

(11:46):

You mentioned the cybersecurity aspects of quantum computing. So quantum computers might be, with Shor's algorithm, be able to break classical encryption methods, asymmetric encryption methods much faster than the classical HPC systems. So that might be the first impact of a quantum computer and the German security agency takes into account that industry should realize that by 2030, it might be that somewhere in the world there might be quantum computers able to break cryptography. So just as a statement to industry. So there's a risk in the future and we can't really know when this going to be realized because no one will tell us if there's already a quantum computer working somewhere in the world being able to break as encryption.

Kyle Fox (12:34):

And I've heard some people refer that as Q-Day.

Dr. Robert Axmann (12:37):

That's Q-Day. Yeah, that might be Q-Day. The point is concerning encryption, and I think you as NXP know far better than me, encryption is not just keys in software and switching a browser or anything like that, but it's also chips in machines, chips in tanks, and chips whatsoever. And those systems need much longer to be changed and to be adapted to newest, for example, like quantum computer. So Q-Day is if it's there, it's too late already. So we have to take into account quantum computing and Shor's algorithm already earlier. But you mentioned another application area, so mobility for example and optimization, that might also be an interesting field for quantum computing. So optimizing, searching in big unsorted lists of items, quantum computers can be much faster when sorting big lists and finding items compared to classical computers. And that might be a good aspect that quantum computers can be used to be much faster than HPC so we can use them to optimize production processes, for example.

Kyle Fox (13:43):

Well that makes complete sense because if you can take an unsorted list of massive data size and be able to cut that down by orders of magnitude, that's going to have huge impacts to throughput of understanding the signal from the noise so to speak, finding out what you need to do with that data. Right?

Dr. Robert Axmann (13:57):

Yeah.

Kyle Fox (13:58):

Well, let's take another leap there. We were talking about use cases and you definitely hit several of the ones that I most often see listed in the press, drug discovery, material science research, financial modeling, optimization problems. Maybe taken in a slightly different direction, when I think about quantum computers are really good at dealing with large data sets and finding and analyzing them, what about for neural nets? Could quantum computers be applied to take some of the processing and energy problems that you have with training LLMs? So the chat GPTs of the world, could quantum be applied to that problem?

Dr. Robert Axmann (14:33):

It's a difficult question, honestly. I think it might be, yes. So we do have projects for example in the area of climate modeling where quantum machine learning might be able to provide additional variables within the model that can't be really easily found with the help of classical HPC systems. And it might be that also in the large language models also quantum machine learning in any way might be helpful. But up to now, we don't have any projects in this area.

Kyle Fox (15:06):

Well, unpack that for me with climate. So you're saying that an HPC that's looking at a climate model, there may be some very hard to work through problems that quantum could be applied to. In my mind I think of that is that there could be an area where it says, "We're going to now hand this over to a quantum machine that can give us much better data with a response back to the HPC to say, okay, this is what that variable means." Is that what you're describing with climate modeling where you have almost a hybrid approach to it?

Dr. Robert Axmann (15:32):

In the research project, we do have a hybrid approach and the problem is that the climate models are consisting of several millions of variables and if we are processing those models in the future with, let me say, steps of some minutes for example, they are exploding, simply exploding. It might be helpful in some ways to simulate or to compute some of the climate variables within the model with the help of a quantum computer. But that's research, that's ongoing research at the moment, so it's not yet clear if we really can show an advantage.

Kyle Fox (16:05):

I understand that one of the main goals of the DLR QCI is to build a strong quantum computing ecosystem. So why is it so important to bring together so many different players from all these different angles to create that ecosystem?

Dr. Robert Axmann (16:20):

In Germany, we do have the situation, we have a very strong fundamental science. So we have universities and the research organizations like Max Planck, Fraunhofer, DLR, for example, and on the other side we do have industries, startups and we have of course research groups within DLR. And with our quantum computing initiative, we are bringing together all those players in two hubs. So we have two hubs, one in Hamburg, there's also an NXP site and one in Ulm, so Southern Germany where we have them working together on the development of quantum computing hardware on the usage of those systems and the development of use cases, trying to transfer those use cases into industry, into useful algorithms and feeding back the experience from using those quantum computers and the algorithms back to the provider of the hardware. That's our idea of working together with users and developers.

(17:14):

We are doing events, so VC events, for example, we are doing a yearly event with the community to exchange with politics with different players, stakeholders to say so, that we can really foster an ecosystem in Germany. I think Germany has really good chances and Europe also to be sovereign concerning quantum computing technologies because all the basics have been done concerning quantum computing in Europe, in Germany, so 100 years ago already. And we are still strong in this, and we as DLR try to, as I mentioned already, transfer from the research groups into the industrial applications, that's our point.

Kyle Fox (17:49):

And you're creating a feedback loop between the harbor manufacturers and the people building the apps. And of course, when it comes to hardcore based science and research and in productizing that, expanding that, Germany is very well-suited for that. As you said, the fundamentals are there. When I think of an ecosystem and I think about a processor has an operating system, it has software, it has tools to program it, to debug it, to write code, do we need a fundamentally different mindset or approach here for say, and I'm just going to use the example, an operating system for a quantum computer versus a classical, or do we actually need to have operating systems that are worse tools? Is there any difference between a quantum and a classical approach?

Dr. Robert Axmann (18:32):

There are differences between the classical systems and the quantum computing systems. In the classical systems, we are working with the operating systems like Windows and we do have sets of instructions that is on classical architectures understood by each processor. And concerning quantum computers, we are on a stage at the moment where each quantum computer has more or less its own set of gates or being able to show his own set of gates at the moment and for the future, it's of course the goal that we have a standard set of gates on every quantum computers that we can have a next layer where we have a classical open chasm interface for example, and then we can go to higher layers where we have just and programming interface that's regardless which quantum computers is behind. You can program the system on a high level language, but at the moment we are a little bit away from this and that's the development approach also.

[NEW_PARAGRAPH]At the moment, we are still on the level of pulses, so if there's anything not working on the machine, if we are not coming along with an algorithm, we have to sometimes change the pulse sequences and we have to modify really hardware low level, but for the future of course it will be an interface in the cloud where we can access the quantum computer with a standard interface and sense the algorithm and get the result back without taking into account what's behind and what machine is working behind. But at the moment, we are not right there.

Kyle Fox (19:59):

It's fascinating to me because the image I had in my head was you could almost see the quantum machine as an accelerator and maybe that's the wrong way to look at it, but it's accessed in the future through a standard API, where someone says, "I have a certain set of functions I want to do," and a classical computer, even a Linux OS could call that and incorporate it into its overall machine or its instructions or its workflow, probably better to say that, just like it might do with any other accelerator.

(20:29):

But what was fascinating to me was the way you described, we're still at the pulse level and I'm old enough to be able to think back to the Apollo computer that helped with the lunar landers in the late '60s. And I was still old enough to understand that we were still at the stage way back in the '60s and the '70s where we would have to either modify the software to work how the hardware is working or change the hardware to do it. And it helped place in my head where perhaps we are on that timeline of development where we are with quantum computers. And I think that's a really fundamental realization for me because it does show a map of where we need to go. Perhaps you're going to get to the future vision you described a lot quicker than we did over the intervening 30 or 40 years from the '60s to the 2000s on classic computers. Would you agree with that or is it still too early to say?

Dr. Robert Axmann (21:21):

It's difficult to say, but of course, I hope that we are coming through much faster. So what you mentioned is that the idea, we call it QPU, quantum processing unit. So it's something like a GPU, so something that you use additionally to your GPU and the QPU is something that's simply in your computer and it takes the part of the calculations that's the quantum calculation. It's not like that at the moment. It might be a future vision, but it's not like that at the moment. And once we finish all our assembly and engineering on the pulse level, I think then we can think about handling this like a QPU. And nevertheless, I think or that's common sense at the moment, that quantum computers in the near future will be more or less additional calculation units within bigger HPC centers solving certain problems really fast, but only that it won't be anything that will be on your desk in the future. It won't replace your mobile phone or your laptop or something like that.

[NEW_PARAGRAPH]And concerning the future, it really depends on how good we are in error correction. So error correction is one of the most pressing problems for the actual generation of quantum computers. So we are still in the noisy immediate scale quantum computing area where quantum computers still lacks the problem of stability. They're influenced by radiation, by thermal problems, and this limits our calculation time on the systems, on the ion traps or on the superconducting systems. And once we overcome this with error correction and maybe with better shielding, better cooling, then we are coming into the time when we have completely stable working error corrected quantum computers or qubits, which we can use for continuous calculation.

(23:07):

And our experts told me that they expect the really interesting point once we have up to 50 or more than 50 qubits working continuously without any errors in the machines, then we will see the quantum advantage. And this depends of course on engineering when we'll be there. So it's not that easy to say. Some expect it within the next 3 to 5 years, some say okay, it's 10 to 20 years. It's really difficult to say up to now.

Kyle Fox (23:36):

Quite a wide range there, but it makes a lot of sense because that's when it explodes, because if you can mass manufacture these, obviously as you said, this isn't going to be in my pocket on my phone, but it's having that stability to be able to rely upon it demonstrably across multiple machines. Well, that's where an ecosystem really gets going because you can hand those machines out or give time on them, whatever, so that people can stably work through some of these problems and figure out what it's best at and how to integrate it and get that innovation cycle going. And I love the idea of a QPU because that really helps place in my head. It's Amdahl's law. It's the idea that within a workload, you're going to have certain areas where you can speed up. Well, quantum computers would be able to speed up certain portions of a workload, but we're not looking for it to run a Windows operating system and play Pac-Man on it. There's specific problems that we're going to deal with.

Dr. Robert Axmann (24:27):

It's just like that. So we have a certain set of algorithms, so mathematically defined problems where quantum computing has the potential to be much faster than classical machines. So I think it's around 40 algorithms that are well-known for math. And now, we have to prove that we really can be also in real life, in real-world problems, are able to outperform HPC systems and this requires ever corrected hardware.

Kyle Fox (24:52):

And that's the great hope there, right? Because I think back to my example, the Apollo computer, I think that in the late '60s, early '70s, people definitely had a lot of different ideas of how computers can help them, but they were constrained somewhat to the level of technology innovation they had, but it took a lot of innovation to get there to come up with new problems that we can solve with that technology that they hadn't thought of at that time. And when I hear you say there's about 40 algorithms, I would make the claim that's the seed. So think what we could apply to it next that we haven't even thought of. And that for me has always been the exciting part about quantum computing.

(25:25):

We've talked a lot about use cases, how this ecosystem can develop and the future promise of quantum computing. So let's talk a little bit about the consortium itself. So NXP, eleQtron, and ParityQC are working together in the QC Consortium and we just recently presented a first full-stack, ion-trap based quantum computer demonstrator, which was made entirely in Germany and I believe it has its own digital twin. Can you explain a little bit what's so special about this demonstrator? Talk to us about what that demonstrator actually does and where it's located and what you think about it.

Dr. Robert Axmann (25:59):

Yeah, well, it's one first ion trap systems that we are getting within the QCI, and it's specific in this way that we have after I mentioned it already, we have two four-qubit systems within DLR, so real hardware. And the 10-qubit system produced by eleQtron, NXP, and Parity will be the next system to be delivered and we are happy once we have it. So it has been already presented and it's still under construction. And once we have it, it's for our research already, very interesting to work on those systems, because imagine the four-qubit systems are, let me say more or less toy systems. You can use this hardware to check the entanglement to work on real hardware, to control the pulses to see how the system is reacting. But with four qubits, it's really a low number of qubits available.

(26:52):

Once we do have the 10-qubit system, I know that some of our researchers are already interested in doing the first algorithmic programs on this machine and to find out how can the 10 qubits be used to solve their, in this case, battery simulation problem and to learn how to program the system because we are expecting bigger systems in the future. So with more qubits, of course. And once you have the bigger system, of course you need already the first example, the first running example with all the small and big problems working on a 10-qubit system. So it's not just research, they are also learning something from concerning battery simulation, but also using the system itself and the interface and the control of the qubit and stability of the system. So that's very important for us to get the system hopefully within the next month.

Kyle Fox (27:38):

Interesting. And you said battery simulation, so what other types of research/demonstrations are being pursued here? Are you still in the process of learning how to program it? Are there particular areas that people are leaning toward that they think will be the first thing to really showcase or is battery simulation the one that you're going to go to?

Dr. Robert Axmann (27:54):

Battery simulation, it's part of the material science of course. And battery simulation concentrates on different aspects of the battery, for example, on degradation of the electrodes within the battery and the different material mixes. And this is something that you can really simulate while on a quantum computer because the quantum computers uses quantum effects to work and battery chemistry is also a quantum effect that can be easily simulated with the help of a quantum computer. So that's one of the reasons that we are focusing especially on material simulation and battery simulation.

Kyle Fox (28:26):

Well, and what a great way for sustainability, a great thing to be looking at. Material sciences has exploded in terms of the amount of innovation over there the last 20 years. To take it to this level, I'm looking at my cell phone right now, if you could make some advances, even if you could get 10 to 20% improvement, say in a battery life.

Dr. Robert Axmann (28:45):

It's a lot.

Kyle Fox (28:46):

That's a lot. And if you could apply it globally, you've just made a huge dent in our carbon footprint, energy production, the whole works. So that would be a huge advancement and an elegant way to show the promise of quantum computing. Up on your website, you saw probably some prototype drawings of what this demonstrator's supposed to look like and what was interesting, all the high technology aside is how clean it looked. It looks like if somebody said, "What does a quantum computer look like?" It matches the drawing in my head. It looks production-ready and I'm assuming that's what y'all are building towards. And I think in the press when you see pictures of quantum computers, you see the towers of copper wires with copper plates and it looks very exotic, but I think the lay person may look at that and go, "What is that? It looks almost like the guts of a futuristic machine," which in many ways it is. But that really struck me as is how polished it looked.

Dr. Robert Axmann (29:36):

When you mentioned the copper, that's usually the cryostat of a superconducting system where you see all the wiring and pipes for cooling the system. You don't see the chip itself, but all the cooling technology around. But it looks fancy, of course. I completely agree. And the QC1 also looks fancy, it looks very clean, but behind of course, it's a vacuum chamber cooling system and the ions are somewhere trapped inside, monitored by a camera and lighted by a laser. But I think nevertheless, it must look fancy because it's fancy technology and you need also to sell fancy technology a little bit.

Kyle Fox (30:14):

Exactly. And I'm a technologist at heart, but I'm also a marketer. So being able to market things and get people that are interested in this even more interested because they see something that not only looks cool, but they go, "That might be something that is at least in my wheelhouse of a real device and I can now comprehend it a little bit better and I could start using it," I think it's super important as the industry moves out of this initial pulse phase as you described.

Dr. Robert Axmann (30:37):

It must look fancy also to be appealing to the people. It shouldn't look like oily old metal, for example. It should look fancy like the future. It should be a little bit Star Trek.

Kyle Fox (30:48):

Exactly. And I'm glad you said it to me, but yes, I am also a big Star Trek fan, so it needs to look like, wow, that just came from the 24th century. That's going to transport people, right?

Dr. Robert Axmann (30:57):

Yeah, exactly. And it attracts people to start a career in this area and to be interested in the technology.

Kyle Fox (31:03):

We're probably still not at the point where you can start looking at multiple universities doing quantum tracks for computer science, but it feels like especially with some of the efforts you're doing that we may not be too far away where somebody can actually say, "This is now not just a research project. This is something I can actually dedicate myself to." Maybe almost akin to where machine learning and neural nets were circa 2005, but there's definitely something there, but there's not a lot that you can really hang your hat on. It wasn't for a few more years that people said, "Wow, we can really make a go of this," and things exploded. Do you feel the same way or do you think we're closer to that aspect or much farther away? Where do you think we are with just the university tracks?

Dr. Robert Axmann (31:46):

I think it's improving and improving, so it's getting better and better. We do see a lot of university education, but also once you started in your job, you can also do additional training from external providers concerning quantum tests. And you shouldn't forget that quantum computing or quantum technology is not just quantum computing. So it's also quantum sensing, for example, quantum cryptography, quantum simulation. So if you go and study for your master's classes, for example, courses with relation to quantum technology, you not necessarily have to go to quantum computing industry, for example, but you can also go to a sensing company like Bosch for example, and develop sensors in this area and cryptography and quantum key distribution, there are other fields where you can also work on, so you don't have to stick to quantum computing. And the amount of education offers is really growing and it's necessary.

Kyle Fox (32:40):

There's going to be a lot of things that are not necessarily building the quantum hard, but they're using it or they're creating things that a quantum system needs, sensing as you described. And just also just modeling. There's a whole bunch of things that people could be working on right now that actually are fungible. They could be useful in a quantum environment, they could be useful in a classical environment. So you could actually have a much richer career because you're adding quantum to it as opposed to only doing quantum.

Dr. Robert Axmann (33:10):

Yeah, it's not just development of the qubit itself, but it's also development of laser systems, it's development of the cooling system, it's development of the electronics, of the cryogenic electronics, for example, that needs to be done. And this is something that is needed in quantum computing, but not only there. So it's cryogenic technology is also needed in other areas. So if you are going to study something related to quantum, it's not necessarily that you have to stick in this area, but you can go somewhere else, develop electronics further systems. So it's really a wide field and it's a future field. It won't vanish on the future.

Kyle Fox (33:44):

Exactly. It's going to be here. And for our listeners that may be entering into university or in the middle of it, or even those that are past and want to try a new career path, take note of this, this is something that is additive to what you may be going after. And I think you've just said it best, it's not going away. We are in the early phases of making this work, but the tech is there that the foundational researchers saw it. And when I think about some of the use cases that we talked about, we just quickly said drug discovery, material science research, battery modeling, climate change modeling, I think it's obvious that from a sustainability perspective, these are some of the toughest, most pressing problems on the planet. Finding new drugs, cancer research, material science, the climate, all of these things can be benefited by continued research with organizations such as yours. So at the end of every episode, we always ask our guests the same question, and I'm very excited to hear your answer, Robert, how do you personally envision a greener world 50 years from now?

Dr. Robert Axmann (34:45):

Yeah, thanks. Interesting and difficult questions. I think we are concentrating today mostly on that we have to stop burning fossil fuel in the future. And I think it's of course a very important point, but my personal view is also that it's not just stop to burn anything, but it's also to, I think we need a change in the mindset that we need to increase consumption. So everyone on this planet I think is consuming so much. So we are buying a new mobile each and every year. We are buying clothes for 5 euro, $5 whatsoever a piece. So I think is it really necessary to consume that much amount of whatsoever of clothes of food and so on?

(35:39):

So my idea would be that hopefully in 50 years from now, people think about more what do they really need to be happy? Is it the amount of stuff or is it maybe more or less the quality of the stuff? And wouldn't it be better to have one lovely piece of clothes instead of 10, which you don't really like, which vanish in somewhere in the building? I think that's very important to think about at this point and think about is there a limit of growth that we should take into account in the future? And I think there is a limit of growth. We shouldn't have the goal to be bigger, faster. That shouldn't be the goal for the future for us. And I think besides this, not burning that much fuel and going for an all-electric world, it's also to take into account the quality of the products and the reduction of the consumption of the overall consumption.

Kyle Fox (36:32):

That's beautiful and I wholeheartedly agree with it. And what I really focus in on is rather than bringing people up to a consumption level, let's bring the consumption level down.

Dr. Robert Axmann (36:42):

And I think this requires a change of the mind of the people because this expectation is that we increase our consumption, as you mentioned. So everyone wants to consume more to become more happy. But I think that's not the solution. Regardless, if we are 10 billion people or 8, is it really necessary to consume that much? And nevertheless, it might be possible to combine this within an electric or full electric world that we have in some areas, for example, transportation, that we can still travel around the world because we are traveling in an electric way using trains, for example, or electric planes maybe in the future, or hydrogen propelled ships, whatever. It might be a bright future, although we are not consuming that much, but it might not be that limiting as people might expect.

Kyle Fox (37:31):

And as innovation comes in, people find new ways to do things. And what's really interesting to me is everything you just said, I'm just looking at my notes of the things that quantum computing can help us with. You're talking about electric planes, you were talking about new ways of moving around, all electric world, the health of the population. Well, that's just a laundry list of the use cases that quantum believes they can tackle. Drug discovery, material science research, batteries, organization and optimization problems, all of that is something that has the promise from quantum.

Dr. Robert Axmann (38:02):

I think the important thing concerning quantum machines or quantum computers to understand is those machines, if they are working, are able to serve certain basic mathematical problems for certain algorithms and for certain application areas. But those algorithms are, let me say the optimization of anything, it will be relevant for many fields worldwide, production, mobility, any optimization process on quantum machine can optimize anything that's modeled within this mathematical framework, and this will improve. So the machine, the quantum computer, will improve different fields of the economy, of science once we can apply a certain algorithm.

Kyle Fox (38:45):

It's fungible, it's the old right wants apply many times. And exactly that, once we get a breakthrough and one area, we can apply in different ways across many others. So it's a gift that keeps on giving.

Dr. Robert Axmann (38:57):

If you succeed in optimizing traffic routing, for example, it might be the same modeling for shipping goods around the world. It might be the same modeling for airplane optimization at the airport. So it's a gate assignment problem. And once you have the algorithm and the problem modeled and it's running on the machine, you can apply it in many different fields and you can support the sustainable future by improving some percent more efficiency within the process. And that's I think it's good news for the future.

Kyle Fox (39:28):

It's great news. It's some of the things that can help give us hope in that we can actually solve some of these things and have a future better world and not 100 years from now, but in our lifetimes. Well, Robert, it has been an absolute pleasure talking with you.

Dr. Robert Axmann (39:44):

If the listeners are interested, so it's qci.dlr.de, so you can find the website, all our projects. Also, of course QC1 and QC2 is the project. And you can also follow us on LinkedIn. We have a LinkedIn channel, Quantum Computing Initiative and we will be happy to answer questions. So please get in touch if you're interested in any aspects of quantum computing. Come to me or contact my team.

Kyle Fox (40:07):

And Robert, thank you for being on the show.

Dr. Robert Axmann (40:09):

Thank you very much.

Kyle Fox (40:10):

Thanks for being here with us and we will see you on the next one.