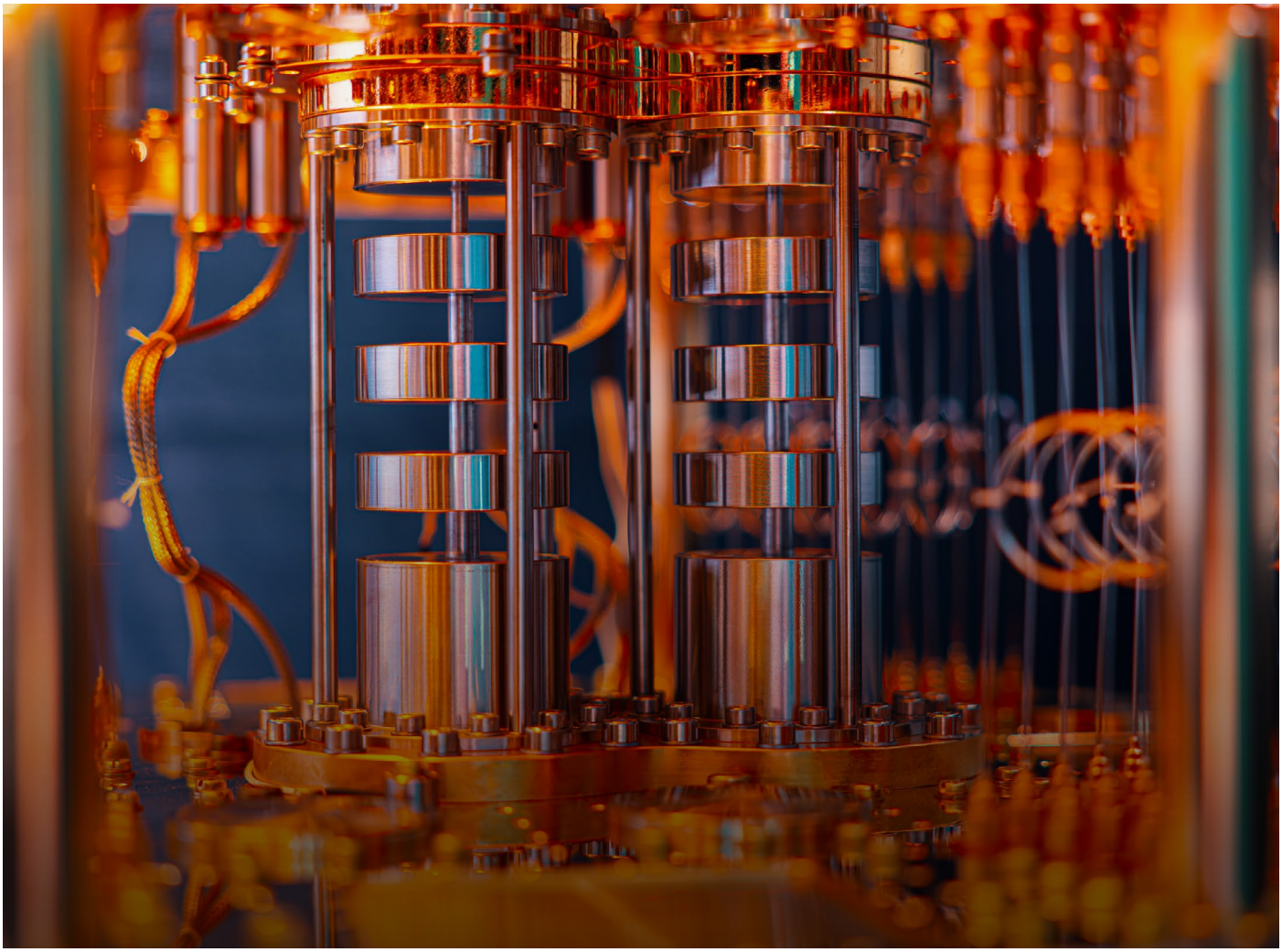
IQM OpenOcean LAKE STAR

NOVEMBER 2022

State of Quantum 2022 Report



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Executive Summary

This State of Quantum 2022 Report, from IQM Quantum Computers, OpenOcean and Lakestar, in association with The Quantum Insider (TQI), is new research exploring how business leaders' readiness for quantum technology varies across key geographies and industries. Quantum computing is rapidly maturing as developments in quantum hardware and software make it an increasingly viable proposition for organizations' infrastructure. Businesses now have an opportunity to be prepared for all the opportunities that quantum technologies have to offer.

This paper offers insights into how quantum firms, backed by public and private funding, can bridge gaps between the speed and direction of the development of quantum technology and what customers are already planning for. The paper is broadly based on data from a survey conducted by TQI on behalf of OpenOcean, IQM and Lakestar in November 2022 (see the "Survey Methodology and Demographics" section for further details).

AT A GLANCE

KEY STATISTICS

66%

of businesses surveyed consider software development to be a main priority for quantum investment.

76%

of respondents agree that the skills crisis is causing a deceleration in innovation in quantum.

63%

of business leaders expect commercial uses of quantum computing within the next 5 years.

91%

of business leaders surveyed are already investing or planning to invest in quantum computing.

Key Takeaways

This research set out to understand a hypothesis on the state of the quantum industry today:

"There is a fundamental gap between the speed and direction of the development of quantum technologies and what industry customers are ready and planning for."

Hype and exaggerated promises cloud our understanding of quantum technology. Many potential industry customers have heard of the technology, without ever going deeper into understanding its value for their business. We partnered with The Quantum Insider, the leading provider of market intelligence on the quantum industry, and their broader enterprise partners, to reach a sample of 174 business leaders from different geographies and industries.

Whilst the knowledge required to complete the survey will have created a natural bias to organizations with a good understanding of quantum technology, our approach allowed us to garner high quality responses with actionable and relevant insights. According to TQI, there are at least 150 enterprises worldwide who show clear evidence of interest and pursuit of quantum.[1]

We asked how, if at all, they are preparing for quantum and what their expectations are for their business. Questions investigated patterns of investment, organizational structure (especially issues of talent and training) and use cases within the business.

The results raised several key conclusions that should be a useful guide for boardroom planning for quantum in the years ahead:

a. As investment figures in quantum hardware and software rise, a thriving ecosystem of industry customers continues to grow – each party backing the technology to achieve commercialization in the next decade with significant R&D budgets.

b. As boardrooms assess the rapid advancement of quantum computing and the multiple opportunities it can offer their companies commercially, a dedicated quantum leadership position of a Chief Quantum Officer will become essential.

c. Having focused leadership will be vital in taking steps to address the quantum skills shortages that are holding back progress and build a long-term people strategy for investment and adoption of the technology.

d. On balance, a high proportion of industry leaders believe quantum technology has the potential for a range of application-specific uses, especially in cyber security, finance, and healthcare.

e. However, there is a renewed focus on the need to support the development and advancement of full-stack quantum technologies. Alongside a prioritization of investment in software, industry customers in our survey view running quantum hardware as currently unsustainable for their operations, pointing to the significant proportion of budgets needed to operate quantum hardware.

[1] *The Quantum Insider, The Quantum Intelligence Platform.*

- **66%** of companies consider software development to be a main priority for quantum investment.
- **64%** of respondents said that the CQO (Chief Quantum Officer) will become almost as or equally as important as the CIO (Chief Information Officer).
- Firms are building quantum teams but adoption is also threatened by a **quantum skills crisis** and talent shortage. **58%** of business leaders surveyed answered that a lack of in-house skills or a qualified workforce is hampering their use and adoption of quantum.
- **76%** of business leaders surveyed agree that the skills crisis is causing a deceleration in innovation.
- Businesses understand the limits of quantum computing, and there remains a significant cohort (**33%**) of respondents that see an **application-specific** future to reach for quantum advantage.
- **10%** of respondents are cautious on there ever being functional use cases of quantum computing.
- **63%** of respondents believe that commercialized quantum computing will hit the market in 5 years. **90%** believe that by 2030, their company's operations will have been transformed by quantum computing, and **83%** predict that commercialized quantum computing will hit the market in 10 years.
- **Significant investment in quantum computing**, with **61%** of respondents planning to invest $1 million or more over the next 3 years.
- The **diverse range of quantum technologies** in today's market allows businesses to make informed choices about which option suits them best:

  1. **68%** of respondents are using or planning to use quantum software applications.
  2. **49%** of respondents are using or planning to use superconducting quantum computers.
  3. **39%** of respondents are using or planning to use quantum-inspired computers.

- Despite excitement at quantum's potential to support businesses in innovation, **streamlining their operations** and identifying process efficiencies, **hardware costs** remain a major blocker to quantum adoption. **61%** of the surveyed view the current costs of running hardware to support quantum computing as unsustainable.

Introductions

We all recognise that claims about quantum's transformative potential are widespread. This confuses matters for uninformed customers, diminishing their ability to realistically investigate and plan how they can use quantum technology. And for investors, it adds an extra layer of uncertainty about which areas are best focused on for investment to develop technologies and support adoption.

One of the elements by which quantum computing functions is superposition: the principle that something can be in two states at once until it is measured.

Despite widespread anticipation and planning about the use cases of quantum – from financial modeling to quantum encryption, advanced air travel logistics to drug discovery and pharmaceutical research – business leaders have always been aware of the challenges ahead.

When we began this survey, which of the two states the majority of business leaders fell into — anticipation vs. cynicism, preparation vs. avoidance — was difficult, if not impossible, to quantify. But, by measuring, we have added much-needed clarity to the market.

Our research sought to add clarity to the market and examine how quantum readiness varies across key geographies and industries. Most business leaders have heard of quantum technology. A much smaller subset have taken steps to look at the possibilities it offers to their organization. We wanted our research to stand out from other studies, by reaching out to this subset and explore deeper, actionable insights - not simply add to market hype.

Our work with TQI and their global partners allowed us to reach 174 business leaders from across a range of geographies and industries, most of whom could provide a balanced view on their pursuit of quantum technology.

91% of business leaders surveyed are already investing or planning to invest in quantum computing. **70%** are using and developing real-life use cases, and **63%** believe that commercialized quantum computing will be adopted widely in 5 years.

There is a clear appetite from industry customers for real-world use cases and applications of quantum. Within this research, there are even signs of customers taking steps to prepare their operations for further commercialization of quantum going forwards. **90%** believe that by 2030, their company's operations will have been transformed by quantum computing.

Management teams are laying the groundwork for that reality: **91% of firms** surveyed have already created, or plan to create within the next year, a team dedicated to quantum. This shift extends right the way up to board level, with **64%** saying that the Chief Quantum Officer (CQO) will become almost as or equally as important as the CIO (Chief Information Officer). Businesses that take steps as early as possible to enshrine this CQO role will be well placed to drive a long-term strategy for investment and adoption of quantum.

Yet our research also made clear where there is a gap between the direction the technology is developing and what customers are ready for. **61%** of the surveyed view the current costs of running hardware to support quantum computing as unsustainable. Industry customers are focused on finding workable, full-stack solutions to match their ambitions for quantum. Little wonder, perhaps, that **66%** of respondents consider software development to be a main priority for quantum investment.

This gap between the quantum industry and the customers is added to by the persistent issue that continues to be a check on progress: firms still lack the in-house skills

and capabilities to manage quantum technologies. **58%** of business leaders surveyed answered that a lack of in-house skills or a qualified workforce is hampering their use and adoption of quantum.

It is now up to the quantum industry to listen to this state of quantum, and take action. Customer interest and appetite to invest in quantum is high. We need to ensure that this engagement is matched by continued progress in developing and bringing quantum use cases to market. Failure to do so risks quantum technology development getting perilously out of step with their prospective users.

As for the quantum industry, private investment in quantum technology has grown rapidly in recent years. Investment in quantum is up fivefold from 2017 to 2021, from a total of $0.4 billion in 2017 to a new high of $2.2 billion in 2021[2] – and it's not slowing down. Total government spend and commitments to quantum technology are in the tens of billions with new programmes and initiatives being announced on a regular basis.

This funding needs to support the most innovative companies, at the earliest stage. It has been gratifying to see Series A or seed funding for quantum firms grow progressively in the last five years: from $65 million in 2017 to $1.1 billion YTD in 2022.[3] Early stage investment is particularly vital for an emerging field like quantum. There is plenty of opportunity for firms with an innovative approach to disrupt the market, connecting the possibilities of the technology with the needs of the customer.

Investment also needs to support the journey towards fully workable solutions for customers, eventually reaching a stage where users have all the hardware and software to get up and running. There are opportunities for startups to cooperate and compete across the board here, from quantum software ($0.8 billion funding YTD in 2022) to the development of quantum computers ($0.9 billion funding YTD in 2022).[4]

The next step comes in how the industry can develop the technology. Customers are looking for a fast lane to quantum advantage, a concrete reality to scope out new applications and access to all the available benefits. By bringing together hardware and software co-design to create application-specific machines, we can place quantum computing in customers' hands, and prepare the ground for future developments in the technology.

Looking ahead, there are a wide range of potential quantum applications on the horizon. It is predicted to one day play a significant role in drug discovery, helping expedite processes for testing and synthesizing chemicals for use in medicine, among other use cases. There is also growing interest in quantum as a promising technology to help find solutions for the climate crisis.

Take, for example, the development of ammonia based fertilizer, which currently accounts for 1-2% of the world's total energy supply. Quantum could play a role in scaling up researchers' efforts to find more sustainable approaches to ammonia production, helping to process far more complex simulations. This is particularly focused on the behavior of FeMoco, a complex molecule that is known to be a key catalyst enabling nitrogen fixation in nature with room temperature and standard pressure. These problems, once regarded as not plausible to fully solve in a manageable period of time, could eventually be addressed in a matter of hours or days.

[2] The Quantum Insider, The Quantum Intelligence Platform.
[3] Ibid.
[4] Ibid. Software figures may be skewed by varying estimates for recent funding for Sandbox AQ.

Other areas under investigation for applications of quantum range from designing more efficient batteries (for example, the simulation of the electrochemical processes in batteries scaled from several thousands of atoms on supercomputers to several millions on a quantum computer) to optimizing energy grids for peak sustainable performance.

Moving these use cases towards mass commercialization will hinge on quantum firms being able to scale. This will require close alignment with customers to shape and understand the problem, ensuring there is a strong bridge between the technology and what customers are looking for. Funding will play a key role here to help firms level up ambitions and scale up growth, as will building strong and lasting strong cross-industry partnerships to share innovative ideas and approaches - as part of the bigger quantum ecosystem.

The Boston Consulting Group estimates quantum computing could create a value of $450 billion to $850 billion in the next 15 to 30 years as technology scales and businesses prepare for the use cases promising to unlock enormous value for the end-users.[5]

Understanding where the industry currently stands is a critical step for any disruptive technology.

That's why we wanted to help investors and decision-makers bridge the gap between the speed and direction of quantum development and what customers are already planning for.

Quantum computing promises to disrupt several key industries. The only question that remains is are we prepared for it? We invite you to read this research report and hear how your fellow business leaders are preparing for commercialized quantum computing.

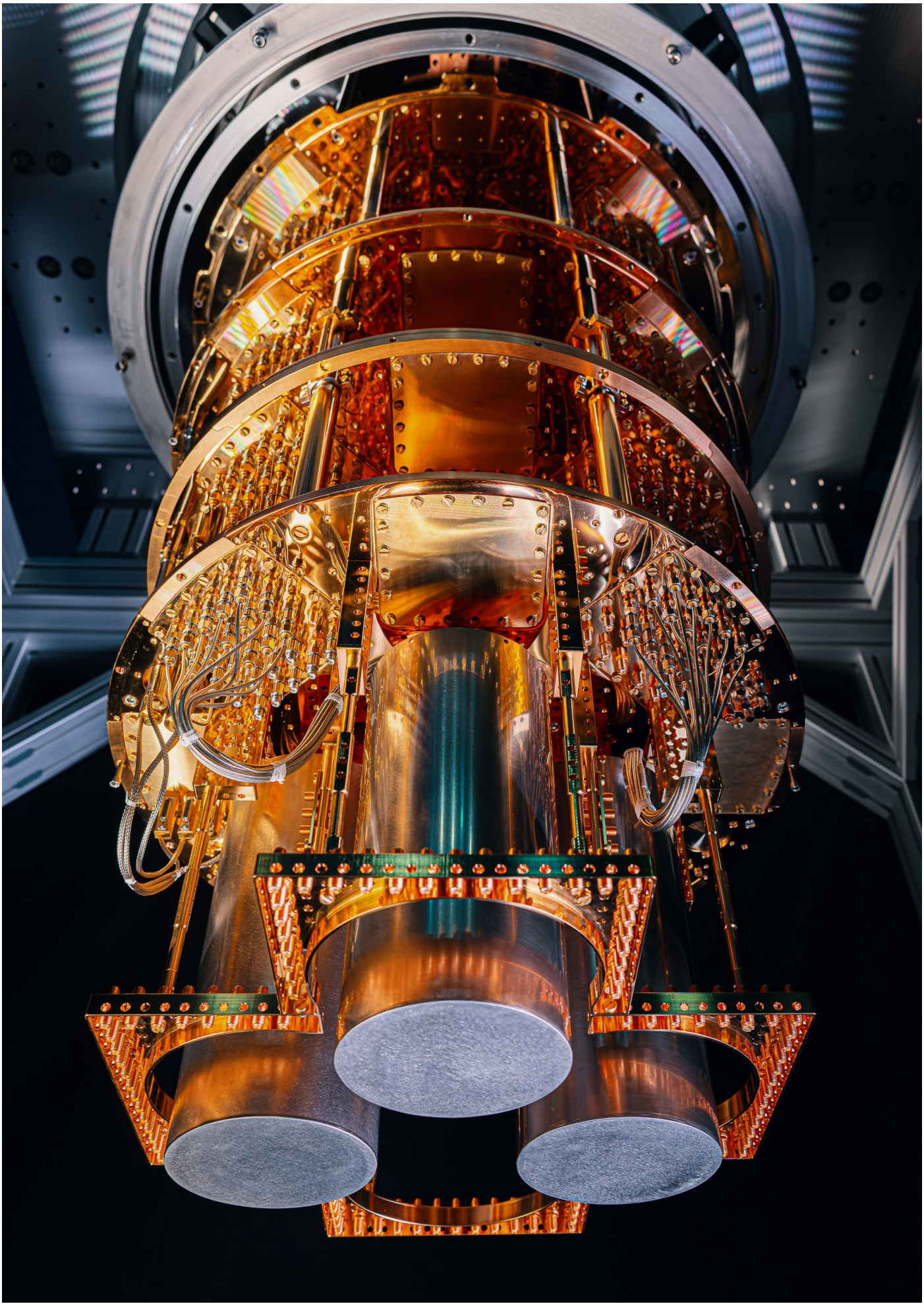
We hope that you're intrigued, inspired, and possibly both at the same time.

Ekaterina Almasque
General Partner of OpenOcean

Jan Goetz
CEO of IQM

Stephen Nundy
Partner & CTO at Lakestar

[5] Boston Consulting Group, The Path to Building Quantum Advantage.



Quantum Industry Perspective - Terra Quantum

The saying goes that software eats the world. That will not be different in the quantum space. We are currently at a stage in the technology's development where, compared to hardware, quantum software offers already substantial immediate potential to optimize and enhance business performance, if we deploy it in the right way. Today's world is built on a broken compute stack, with classical algorithms running on classical computers. We are being held back from solving some of the world's biggest, most critical problems by relying on this classical approach to computing. Quantum holds the solution. The issue remains how to execute on the technology. We need a full compute stack built on quantum, but quantum hardware isn't really scalable yet. That raises the question: how we can deploy quantum software today to deliver real industry performance enhancements.

Industry leaders are tired of discussing quantum technology developments measured in 5 to 10 years or even more. Business leaders want to see real-life application and tangible solutions today. At Terra Quantum, we are committed to delivering on that vision, unleashing the power of quantum technology to provide strong and meaningful solutions and enable organizations already today to unlock some of the quantum potential.

Our unique hybrid approach with our subsidiary QMware, the world's first global quantum cloud, gives customers access to both current quantum hardware and simulated qubits. By combining running algorithms on native and simulated qubits, we can realize substantial better business performance by quantum applications. Our algorithms sit within three key categories: optimization, simulation, and machine learning. We provide end-to-end capabilities in quantum algorithm design, quantum computing and quantum security that are geared towards delivering next-level performance for businesses, today.

It is crucial to double down on the commercialization of quantum now as the technology is continuing its growth. There are broad and wide-ranging potential applications of the technology, providing solutions to a variety of billion-dollar industries, including Logistics, Aerospace, Financial Services, Automotive, Chemicals, Utilities and Healthcare. Many of these firms share common problems with making the most of complex data sets and a sprawling web of requirements. Quantum algorithms have potential use cases that can be extended and replicated across different industries. Enhanced imagery cognition and recognition, for example, using quantum can be applied both in self driving vehicles and to significantly enhance medical diagnosis. Separately, we have worked with a European industry leader on optimizing the route planning of trucks to cut down on empty miles, minimizing costs and supporting sustainability goals at the same time.

Looking ahead, the future is bright for quantum. Quantum software has great potential to grow and thrive. Quantum hardware continues to scale, accelerating performance as native quantum chips start to advance and eventually outperform simulated qubits. One of the biggest challenges we have as an industry is winning over the unconvinced, those potential customers who do not see a future for themselves with quantum technology. The key to doing so is about speaking their language. Connect the technology with their priorities. Customers ultimately care about driving business performance. At Terra Quantum, we see ourselves as a business and performance enhancement company first, quantum company second.

Standing at the very beginning of this revolution we feel the excitement – and responsibility – for the applications and tools we are developing. Europe has a great opportunity to lead this journey, building a strong and thriving ecosystem of disruptive startups and fostering European tech sovereignty. We are ready to play a leading, independent

role in the quantum revolution and to be the trailblazer in technology solutions and real-life applications, shaping a better future for humankind to prosper.

Markus Pflitsch
CEO & Founder at Terra Quantum

The Big Picture: Trends In Adoption & Strategic Planning

Business decision-makers who responded in this survey show a huge amount of faith in the potential of quantum and seem confident that it will provide tangible benefits before long. This confidence is apparent not just from their stated beliefs, but also (and perhaps more tellingly) from where they invest their budgets and how they position their organizations. Companies across sizes and verticals are currently going to great lengths in order to make sure that they are in as strong a position as possible to take advantage of imminent advances in quantum technology.

The IQM-OpenOcean-Lakestar survey revealed a high appetite from businesses for investing in real use cases and adopting the technology. **70% of business leaders surveyed said they are using and developing real life use cases.** Just **4%** are not using and have no plans to adopt quantum in the next 5 years.

Customers are taking the necessary steps to prepare for and plan expansion of quantum computing in their operations. **77% of respondents said they were confident that their organization was prepared to use quantum computing.** Leaders in the UK are more confident in their organization's quantum readiness (**85%**) and preparedness than leaders from the United States (**78%**) or France (**69%**).

This preparation is essential for quantum readiness. Businesses must keep one eye on the horizon as we continue to progress in quantum computing development.

Businesses are backing this up by taking concrete actions to make themselves quantum ready. **91% of business leaders surveyed have either already invested in quantum computing or plan to do so.**

Major corporations are backing quantum as an essential component in the future of their industry. For example, Boeing has partnered with IBM to accelerate the time it takes to test and optimize materials. This essential component of the aerospace industry relies on months' long timescales to test and certify materials for use in planes, slowing innovation every step of the way. Quantum computing is being backed by Boeing to improve the efficiency of these evaluations of aerospace materials, including more advanced capabilities to understand a material's reaction to environmental conditions, as well as estimated service life and performance.[6]

In our research, **83%** of companies are devoting at least 10% of their R&D budgets to quantum, while **80%** plan on investing at least half a million dollars and **61%** plan on investing $1 million or more into quantum over the next 3 years. The amount of money that these companies are investing into quantum computing is therefore significant both as a proportion of total Research and Development spending and in absolute terms.

This varies by geography. Businesses in the United States are more than twice as likely to invest $20 million+ than their UK counterparts (**13%** vs. **5%**). Variations around the world reflect differences in the quantum ecosystems, with notable research hubs in Europe, the United States, and China. There is also the question of concentration of enterprise users, with many quantum firms drawn to the large multinationals in the United States & China.

Investment from the private sector is being backed up by significant public funding for quantum. According to The Quantum Insider, the top 5 global government backers (mix of deployed and announced) for quantum include:

[6] *IBM, IBM Quantum Summit 2020: Exploring the Promise of Quantum Computing for Industry.*

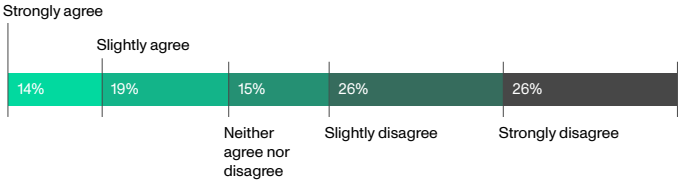
1. China - ~$5.0 billion+[7]
2. Germany - $3.0 billion
3. United States - $2.8 billion
4. United Kingdom - $1.2 billion
5. The European Union - $1.1 billion[8]

Businesses generally seem to feel that their investment in quantum technology is having the desired effect. **67%** say that their quantum strategy consistently meets or exceeds its goals (compared to **10%** who say that theirs does not).

For the businesses who are not satisfied with the results that their quantum strategy is producing, the reasons most commonly identified as responsible relate to several key areas:

- Shortages of skilled professionals
- Funding
- R&D
- Time

To what extent do you agree or disagree with the following statement: Quantum computing will only achieve application-specific usefulness for businesses.

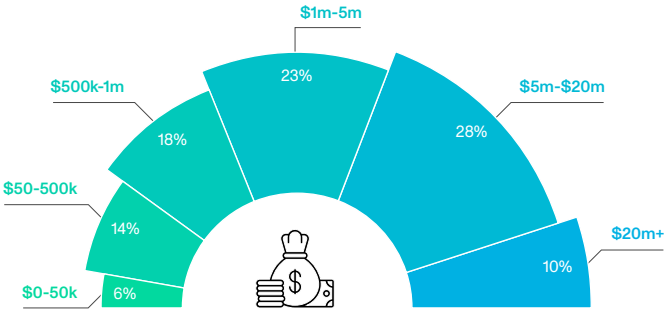


State of Quantum 2022 Report - IQM Quantum Computers, Open Ocean and Lakestar (n=174)

These areas of shortage closely mirror business leaders' key priorities for quantum over the next 3 years. The top 3 strategic priorities for quantum are accelerating R&D cycles/decreased time to market (**53%**), recruiting technical staff for quantum technologies (**52%**), and expanding funding to invest in product/solutions development (**44%**). Recruiting more technical staff would, of course, help to address the issue of talent shortage, while the acceleration of R&D and expansion of funding will help to scope out new use cases, aid development, and generally drive its adoption across the business.

We can see that businesses are taking action to prepare for quantum computing by investigating and starting to roll out new use cases for the technology across their business. It is important that obstacles do not dull ambition, and firms continue to look for new partnerships and opportunities to reimagine what is possible with quantum computing.

How much does your organization plan to invest in quantum over the next 3 years?



[7] N.B. Exact figures are disputed and based on limited sources.
[8] The Quantum Insider, The Quantum Intelligence Platform.
All figures are estimates.

The Journey to the Quantum Era, an OpenOcean Perspective

As an early stage investor in frontier technologies, OpenOcean is keen to support emerging European leaders in the quantum computing space. We are strong believers in anchoring nascent industries by investing in winning teams. It is our mission to help these teams build a strong ecosystem based on their technology platform, accelerating long-term adoption and growth. Our founders learnt the value of this approach firsthand, when they were involved in setting up both MySQL and MariaDB, the "M" in the LAMP stack, which became the foundation of the internet as we know it today.

When IQM Quantum Computers spun out of Aalto University and VTT Technical Research Centre of Finland in 2018, OpenOcean bought into the vision that quantum computing will revolutionize the high-performance computing world. Today we continue to support this vision with amassing positive evidence that we are indeed on a one-way journey to a quantum era; most recently by participating in IQM's €128 million Series A as they progress towards building Finland's first 54-qubit quantum computer. Due to their unique co-design approach, IQM's quantum processors can greatly reduce hardware requirements such as qubit count or gate depth compared to conventional machines.

We are also seeing successes by other players, notably including IBM's recent announcement of the largest ever 433 qubit machine. The findings from this survey demonstrate that the market is accepting this evidence with only 10% of survey respondents being cautious that functional use cases will ever come and 63% of business leaders expecting to see commercial use cases in the next 5 years.

The hardware battles are being won at the processor level but there are still many challenges to scaling. As OpenOcean is traditionally a software investor, it excites us that a lot of these are software challenges and 66% of companies consider software development to be the main priority in quantum investment. Organizations will need to start thinking strategically how they will operate in the quantum era. Many of the benefits of the quantum advantage are still being determined but it is important that organizations begin understanding how quantum software can and will be integrated into their existing stack.

It can be useful to draw analogies between quantum and classical paradigms to project software requirements to scale, from the NISQ era to application-specific machines to fault-tolerant generalized quantum computers. To disprove the 33% of businesses that believe we will only ever achieve application-specific usefulness, we will require a quantum operating system as the gateway to high-level applications. This may be further in the future, but we are already seeing the software component pieces emerging alongside hardware at the control and architecture levels, with a lot of activity from the startup ecosystem and larger players alike.

At the control level, a key issue is the stability of qubits that are sensitive to noise and suffer from imperfections across the system which today results in a tedious manual process requiring highly-skilled scientists. Due to this, there is significant scope for automation of qubit tuning and optimisation - this will only grow as we scale to larger numbers. While this is something that could be developed internally by hardware providers, we are seeing software startups gain traction, the largest being Q-CTRL from Australia with $43.4 million of funding from the likes of Airbus, Sequoia China, and In-Q-Tel.

We can additionally look at the architecture level for short term software plays, where in the long term we expect to see quantum kernels, error correction, and Q-RAM. There are a number of software startups here doing work that's essential to unlocking a multi-billion dollar quantum com-

puting market. The most mature company is Riverlane from the UK, having raised $24.1 million from Amadeus, Molton, and Cambridge Innovation Capital. Riverlane is focusing initially on error correction, which also aims to solve the inherent instability of qubits, with the long term goal to become a general quantum operating system.

There is strong emergence of software at the higher level, with the likes of Google, AWS, Microsoft, and IBM launching open source quantum circuit programming and even early machine learning frameworks. It's great to see these developing and with an emphasis on open source to help drive the quantum software community. However, at this level simulators are still commonplace and hardware details severely affect results.

Looking deeper down the stack is where we can find the essential software glue that will allow these frameworks to run efficiently on scaled-up quantum hardware. It is at this level that we will need to see significant investment over the coming years for a smooth journey to the quantum era.

Ekaterina Almasque
General Partner at OpenOcean

The Benefits and Opportunities of Quantum

Quantum is a broad category encompassing an enormous range of technologies, each offering varied possibilities for businesses. Nevertheless, there are trends which are apparent in what areas businesses are investing in, the different ways in which quantum technology is being rolled out, and the benefits businesses are starting to see.

When it comes to investment, there are many different aspects of quantum which could potentially have funding focused upon them, but some will naturally not yield as great returns as others. As quantum technology develops further, it is very likely that the areas which are seen to hold the greatest promise could change dramatically.

Currently, however, the trend is that end-users are seeking full-stack solutions to their business problems, making software investment a favorable proposition alongside hardware commitments. **66% of companies surveyed consider software development to be a main priority for quantum investment**, with application development the second most likely to be thought of as such (by **54%** of companies) and expanding the company's internal talent pool the third most (**49%**). This relative prioritization of application and software development may be due to the high costs involved in quantum hardware development and the need for specialized skills and tools, resulting in the desire to leave physical manufacturing to hardware experts.

According to data from The Quantum Insider, private investment in quantum software rose significantly from 2017-2022, from <$50 million (2017) to >$700 million YTD in 2022.[9]

When it comes to where business leaders think they will invest in 5 years' time, the trend is largely similar, with software development and application development being the most likely to be considered investment priorities (considered as such by **57%** and **53%** respectively). One change from the current priorities is that building the company's own infrastructure becomes slightly more valued (considered a priority by **47%**), while expanding the internal talent pool becomes slightly less likely to be considered a priority (down to **39%**). This could suggest a long-term willingness to work with external service providers to integrate the necessary expertise into the respondents' businesses.

A number of competing approaches to building quantum computers are being explored or invested in by various research groups and companies around the world. One broad division between approaches has been those based on gate models, in which quantum structures are created using qubits and problems are solved with quantum circuits, and approaches such as quantum annealing, in which problems are solved with systems that can optimize to the lowest energy state.

Gate-based quantum computers are much more difficult to build and maintain, but offer far more powerful and flexible potential uses, while annealers offer less flexibility in application, but far greater ease of creation and maintenance. The category of gate-based computers can be further divided into a number of approaches. Some function by using superconducting electronic circuits kept at extremely low temperatures to create qubits, others function using ions trapped in electrical fields, yet others use spinning charge carriers (spin-based quantum computers). Other approaches include using photons (photonic quantum computers), neutral atoms, and others.

At this point, it is obvious that the race is still on for one of these approaches to overtake others in building a practi-

[9] *The Quantum Insider, The Quantum Intelligence Platform.*

cally-useful and commercially-viable quantum computer.

Nevertheless, our research identified that one approach is dominating the attention of businesses – superconducting quantum computers. **49%** of surveyed businesses are either using them right now or planning to use them in the next 5 years, a far higher number than other types of quantum computer. The next most successful are trapped-ion quantum computers (**24%**), quantum annealers (**23%**), and spin-based quantum computers (used or planning to be used by **22%** of businesses). All other gate-model quantum computers are only used or expected to be used in the next five years by a combined **20%** of businesses.

More companies in our survey are using or planning to use quantum software applications (**68%**) than are using or planning to use any individual type of quantum computer. Quantum Software Development Kits (QSDKs), which are used to develop quantum algorithms, and quantum-inspired technologies like quantum emulators or "digital annealers" are also more widely used than most types of quantum computer, at **46%** and **39%**. This shows a clear interest in end-users looking to experiment with quantum and quantum inspired technology.

As quantum hardware capabilities advance, research institutions across the world continue to push the commercial applications of quantum computing into supercomputing and HPC environments. This is, as we have seen from the business leaders surveyed, enabling a new era of quantum software applications, made possible by exponentially more powerful machines for them to run on.

Germany's Forschungszentrum Jülich (FZJ) research institute broke an important milestone in the European quantum space in January 2022, when it put the continent's first quantum annealer with more than 5,000 qubits into operation. This was the first example of a commercial quantum system in Europe, and its designers aim to integrate it into their supercomputing infrastructure. If successful, this could be an example of a quantum computer working directly with a supercomputer, and would have direct commercial applications.[10]

Looking elsewhere, IQM and Leibniz Computing Center (LRZ)'s Q-Exa project is scheduled to deliver a state-of-the-art 20-qubit quantum computer based on superconducting circuits and will be integrated with an exascale system.

Another impressive example of gate-based quantum computing is the University of Science and Technology of China's "Zuchongzhi 2.1", unveiled in 2021. Zuchongzhi 2.1 has 66 superconducting qubits and has been estimated to be millions of times faster than classical computers.[11] For certain complex calculations, it can achieve in a matter of hours what would take years for the world's most powerful supercomputers.

When it comes to practical arrangements for quantum hardware, the most common set-ups (used by **49%** of businesses) are hybrid ones with a mixture of on-premises and cloud-based infrastructures. Being entirely on the cloud is the second most common arrangement (**26%** of businesses), while just **18%** use an entirely on-premise infrastructure.

[10] Forschungszentrum Jülich, Europe's First Quantum Computer with More Than 5,00t Qubits Launched at Jülich.
[11] Xinhua News, Update: China achieves quantum computational advantage in two mainstream technical routes.

Cloud computing has made quantum computing accessible for the industry. Cloud provides companies with affordable access to the processing power of quantum, trainings and the ability to explore proof of concepts for some of the biggest challenges facing businesses. Known as Quantum-as-a-Service (QaaS), this has a huge transformative potential.

As developments in access toolkits reach maturity, we will also reach a stage with "seamless" integration where "mainstream applications will be able to call upon quantum-trained models, simulators, or optimisers in just the same way they interact with compute clusters or supercomputers today."[12]

A hybrid model with on-premise systems combined with QaaS could be instrumental to quantum's future utility for business. This model will also address the business leaders' concerns on quantum hardware costs. **61% of business leaders see the current costs of running hardware to support quantum computing as unsustainable for their business. Indeed, 65% of respondents indicated that more than 20% of their organization's technology budget is taken up with costs associated with running hardware for quantum computing.**

As storm clouds gather on the global economy, managing these costs will be crucial to encourage strong and sustainable uptake for quantum technology.

Once businesses have their quantum infrastructure set up, they are scoping out a range of different uses for the technology across their operations. The use cases which businesses are most likely to investigate are using quantum for analytics and statistical modeling (**56%** of businesses), for R&D (**54%**) and for optimizing supply chains (**35%**).

Examples from Japan Post Bank, Mercedes-Benz and Mitsubishi Chemical, to name a few, are quite revealing here. Japan Post Bank recently launched a project with A*Quantum, a startup that specializes in software development technology for quantum computers, to optimize the flow of truck dispatches between post offices.[13]

Organizations are increasingly ambitious in reimagining how to utilize quantum. For example, both Mercedes-Benz and Mitsubishi Chemical have partnered with IBM to scope out using quantum computing to optimize battery chemistry.[14]

These use cases are driven by a range of benefits surveyed business leaders most expect to see from quantum:

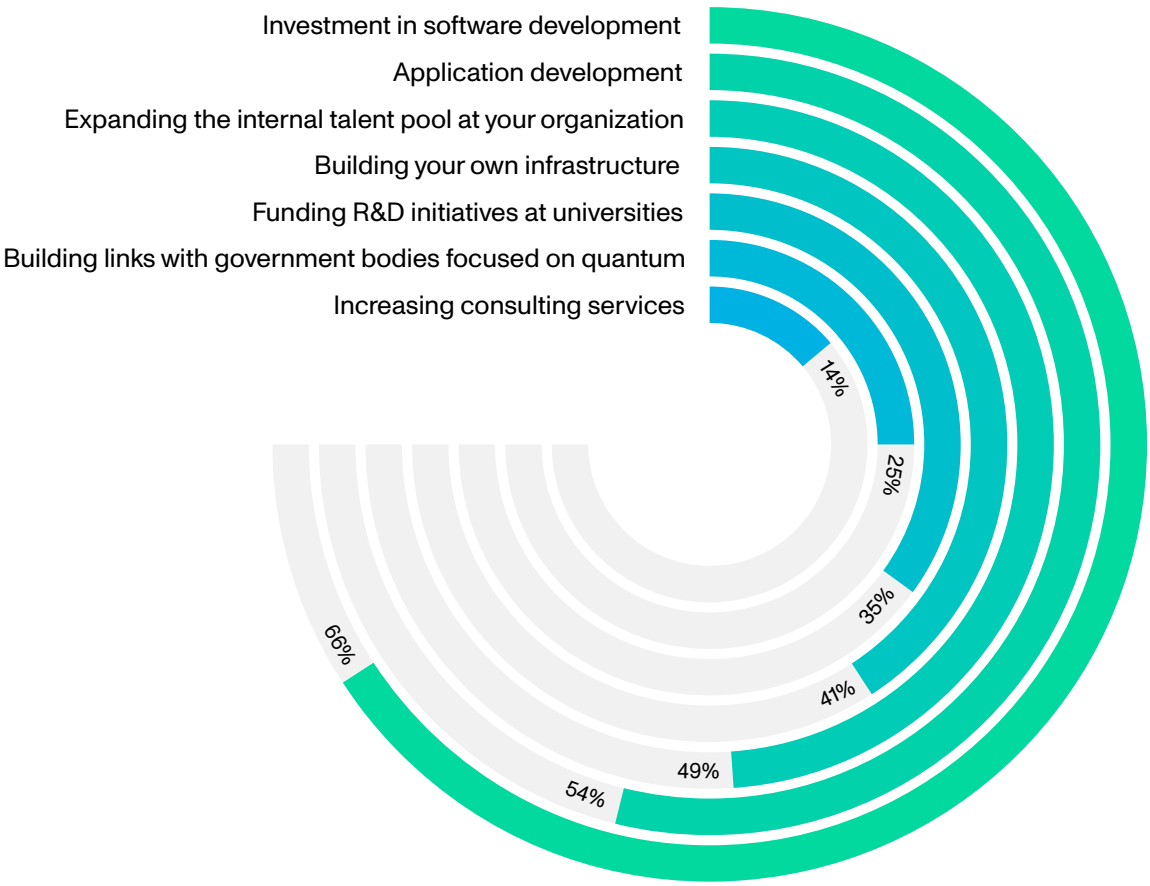
- **56%** expect the ability to solve completely new types of problems
- **53%** business leaders expect greater efficiency of operations
- **52%** predict improved speed and resolutions of highly complex problems
- **43%** anticipate reduced time for processing data

There is a clear link between these benefits – they all relate strongly to processes being performed in a more streamlined manner or with greater speed and efficiency. It seems very likely that the desire for improvements in this regard is a key motivation and driver of the quantum investment described in the previous chapter.

[12] IT PRO, Getting started with the quantum cloud.

[13] The Quantum Insider, The Quantum Intelligence Platform.
[14] Forbes, IBM Quantum Is Helping Businesses Prep For A Quantum-Powered Future.

Where are the main areas your organization will direct its quantum investment over the next 3 years?



State of Quantum 2022 Report - IQM Quantum Computers, Open Ocean and Lakestar (n=174)

Fastlane to Quantum Advantage - IQM Quantum Computers

Large-scale scientific computation is in transition. Fitting more transistors onto a microchip will become extremely hard and expensive in the next decade and will ultimately become impossible. This difficulty is starting to hinder technological progress sooner than we realize.

IQM's stance is that we are nowhere near the computational limits of our time. With our full-stack approach to building quantum computers and delivering them to your premises, with our quantum-acceleration to high performance computing centers and with our co-design approach, we can create a fastlane to quantum advantage.

QUANTUM ACCELERATION FOR HPC CENTERS

Our quantum integration capability enables us to combine the best of both worlds, classical high-performance computing and quantum computing, in which certain computational tasks are specifically assigned to quantum processing units (QPUs), both technologies running in parallel. This combination will speed up overall computational performance where specific parts of exceedingly difficult computations are addressed by a QPU, exponentially accelerating those tasks.

DELIVERING FULLY INTEGRATED ON-PREMISES QUANTUM COMPUTERS

Our offering is also unique, as IQM's quantum computers can be located at your premises and you get full and secure access to the hardware, thus accelerating your research capability and speeding up innovation.

We have a world-class team of quantum experts to train the customer personnel on the build, hardware, and software-algorithm operations as well as safe and effective maintenance. With our experience in building national programs, we provide an expedited way to gain a significant lead in building your national quantum ecosystem.

ACCELERATING INNOVATION THROUGH APPLICATION SPECIFIC CO-DESIGN

As this research has also highlighted, one of the most demanding competitive struggles for any company is prioritizing the right problems, the right value drivers, and staying ahead of the curve as the pace of development accelerates. The challenge is to adopt the right technologies, keep innovating, and maintain continuous improvement to stay relevant. Great companies are constantly looking at problems from diverse angles and investing in unconventional methods to innovate more quickly and offer their customers more value.

HOW TO PREPARE YOUR COMPANY FOR THE QUANTUM AGE?

Today, it has become apparent that building critical knowledge for the upcoming quantum era is becoming imperative for major industries and leading organizations. It is just too big of a transition to ignore and omit when the pace is accelerating. The most convenient and fastest way to start building your quantum readiness is to find a partner with the right technological capability and begin uncovering entirely new avenues for accelerating innovation.

At IQM, we partner with forward thinking enterprises on innovation projects where quantum computing expertise and business design meet to solve the most demanding applications. This innovation means that, within the partnership, we will co-design optimal adaptations of quantum hardware and algorithms to address industry-relevant problems.

The aim is to bring quantum advantage to business problems with optimized algorithms and application-spe-

cific quantum processors that classical supercomputing resources simply cannot address alone.

The important question for business leaders is which quantum approach to choose?

Finding a partner who understands your problems, is pushing the boundaries to innovate and can deliver business results. With our co-design approach and the recently announced qubit type - unimon qubit, we constantly innovate and boost quantum computers towards useful applications

Manufacturing the quantum processors in our own quantum fabrication facility in Espoo, Finland gives us tremendous flexibility and the ability to make sure the chips' quality passes the highest requirements and we are able to innovate at a faster pace.

Another important advantage of quantum technologies is the sustainable solution to supercomputers' energy challenge. Reducing the energy consumption of data centers and servers that contribute significantly to the growing climate crisis.

As the global competition over quantum leadership becomes more important in the coming years, now is the perfect time to start building quantum readiness for the future. I'm confident that Europe will lead the world into this quantum era with quantum computers from IQM.

Dr. Jan Goetz
CEO and Co-founder
IQM Quantum Computers

Building a Quantum-ready Workforce of the Future

Firms seeking to advance towards quantum face an abundance of challenges. The lack of adequate qualified experts makes building quantum teams extremely difficult. Without the appropriate teams in place, there is a risk that both the adoption of quantum and the research and development of this technology will be slowed.

In September 2022, the World Economic Forum (WEF) released their "State of Quantum Computing: Building a Quantum Economy" Insight Report, discussing the increasing difficulty of finding "qualified individuals with previous work experience in the world of business or engineering in an already scarce talent pool" as "companies struggle to find people with the right skills for new positions in the emerging quantum job market."[15] However, there is cause for hope. Despite the predominance of highly technical roles, "more diverse profiles, such as marketing and sales roles requiring prior work experience have begun to appear, showing that the market is maturing."[16]

This report corroborates these findings from WEF. Our research found that **91% of firms** have already created or are planning to create teams that are structured around quantum technology within the next year. Once a team is built, however, other obstacles arise. There is a disagreement surrounding the most important roles within these teams. Whilst **31% believe Quantum research scientists** and **18% believe that Quantum business translators** play the primary role within a team, **38% suggest** that the key role should be given to **Quantum software engineers**. Uncertainty around how to structure the changes as quantum technologies are phased into the workplace may slow its adoption by businesses.

Talent attraction is also becoming a prominent issue as quantum grows. It is increasingly difficult for firms to employ suitable people that are capable of doing what is required of them. **58%** of business leaders surveyed answered that a lack of in-house skills or a qualified workforce is hampering their use and adoption of quantum.

This is inhibiting growth right across the industry. **76% agreed that there is a skills crisis in quantum computing talent which is slowing innovation**. They believe that this issue is something that needs to be brought to the forefront and addressed as a priority for all leaders. When asked to elucidate about how they skills crisis is slowing progress and innovation, qualitative comments from respondents include: "hiring is difficult", "delayed execution", and "existing team forced to do more work".

Government funding for quantum — distributed most heavily between China, the US, the UK, and the European Union (EU) — shows the push to increase the available talent pool by expanding access to the technology and enabling accelerated research.

The UK Government was one of the first to build a national quantum strategy, the National Quantum Technologies Programme (NQTP), in 2014. That programme has now reached nearly £1 billion in investments.[17]

Meanwhile, in 2020, the United States Government — one of the many countries pushing to establish quantum world leadership — committed to spending $625 million on five quantum information research hubs.[18]

[15] World Economic Forum, State of Quantum Computing: Building a Quantum Economy Insight Report.
[16] Ibid
[17] The Quantum Insider, The UK National Quantum Technology Programme Explained.
[18] Energy.gov, Department of Energy Announces $625 Million for New Quantum Centers.

And in the EU, there is sustained investment from the bloc to expand adoption of quantum computers, with the European High Performance Computing Joint Undertaking recently announced the selection of six sites across the EU to run the first EuroHPC quantum computers.[19]

This work has been mirrored by efforts across the private sector to nurture the next generation of quantum research and talent. Such investment can be seen both in funding and collaboration for quantum startups, and in funding for research initiatives in universities worldwide. Over the last four years, Royal Bank of Canada has followed this road with funding for quantum research at the University of Waterloo and new partnership with quantum software startup Multiverse Computing - all part of its effort to solve the most complex challenges of the financial sector with quantum computing.[20]

Tackling the skills crisis hinges on firms' access to quality quantum education and training. However, **45% of firms primarily rely on in-house specialists to deliver this work**. This presents a long-term problem. Primarily, there is increased pressure on specialists to take on additional responsibilities where companies are currently shorthanded. On top of these duties, they are also relied upon for quantum education and training among not only the existing employees but also for new starters. Partnerships with external organizations might offer these firms a short-term fix to this problem as they take the necessary steps to build and grow their quantum teams.

Leadership vision and strategy on quantum is fundamental here. The leadership sets the tone on quantum and provides the structure and direction for development for the business. But again, there is disagreement between businesses on who should be responsible for driving this progress and innovation.

Much of the disagreement centers on whether quantum will fall within the remit of the CIO and IT, or whether there will be a need for a new dedicated role - a Chief Quantum Officer (CQO). The CQO role has appeared primarily at organizations focusing on quantum, but its proliferation may not be confined to research and development. Speaking to The Quantum Insider, Shai Philips, President of Psirch, said, "As of now, it seems this function has been largely restricted to new companies developing quantum technologies... [but] that's not to say larger, more mature companies committed to the early adoption of quantum... won't begin to create similarly high-ranking titles, possibly even at the C-suite level, for Quantum leads."[21]

29% believed that the CIO's role will include quantum. Alternatively, **64% said that the CQO will become almost as or equally as important as the CIO**. Defining clear roles and responsibilities on hybrid computing and quantum will ensure the technology does not fall off businesses' radar and the groundwork is set for the progressive commercialization of quantum in the decades ahead.

According to the survey, "finding the necessary expertise" was the principal concern amongst business leaders on the question of making quantum computing a reality and making it suitably functional to be integrated into businesses. This concern even surpassed cost-effectiveness, technical constraints, and market competition.

[20] EuroHPC, Selection of six sites to host the first European quantum computers.
[20] The Quantum Insider, The Quantum Intelligence Platform; Financial Post, Bank of Canada taps quantum computing startup to tackle complex financial problems.

[21] The Quantum Insider, The Rise of the Chief Quantum Officer and The Prospect of Quantum at The Governance Level—an Interview with Shai Phillips, President of Psirch

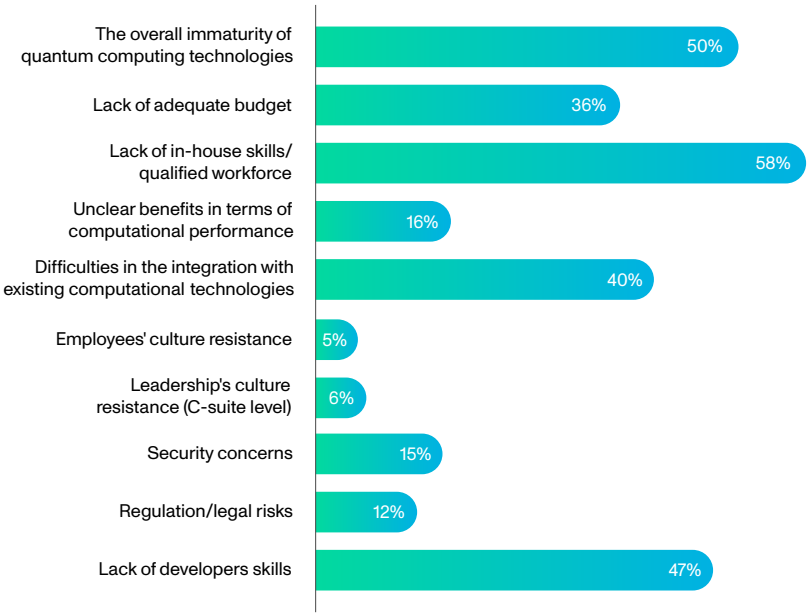
When considering quantum adoption, it is clear that the concern surrounding gaps in essential talent are dominating. Results showed three prominent barriers to adoption:

1. **The lack of in-house skills or a qualified workforce.** Such a shortage risks companies taking half measures, becoming reluctant or even unwilling to transform and embrace quantum computing.

2. **The overall immaturity of quantum computing technologies.** There needs to be concerted action across both private sector and government to drive the development of quantum technology standards and industry consortiums. Businesses should be brought into this discussion in the form of advisory councils and think tanks to create a holistic quantum strategy. Businesses need a clear guidance and roadmap to measure the quantum progress, and when they will be ready to realize some or all of the benefits.

3. **The lack of developer skills.** Developer roles are critical for the management and progression of quantum computing. Without the right people in place to operate the different technologies that are used in quantum computing, it is likely that it will be delayed from commercialization even further.

> What barriers (if any) are hampering the adoption of quantum computing technologies in your organization?



State of Quantum 2022 Report - IQM Quantum Computers, Open Ocean and Lakestar (n=174)

The Way Ahead: Business Adoption of Quantum Computing

Businesses that are considering the movement towards quantum computing understand its limitations. Our research showed that many businesses are split. In fact, **44% think that the current software and tools available are not sufficiently advanced to deliver real-world applications on quantum, compared to 44% who thought they are sufficiently advanced**. There are a range of issues highlighted by business leaders, believed to impact the utility of software and tools. These include:

- Cost efficiency
- Hardware issues
- Investment
- Talent

The central theme we explored in this survey concerned any divide between the technological advancements of the quantum industry, and the ambitions and plans of end-users. When asked if they think the current discussion about quantum computing oversells its realistic capabilities, it was a mixed response. **More than half (56%) of business leaders actually disagreed with the overselling**. For an early technology, this is clearly a strong, and growing, belief that the current discussion about quantum and all its potential has not gone too far. Indeed, customers are ready, and slowly planning for, quantum across the economy. Based on the thoughts of the business leaders we surveyed, the top 3 sectors ripe for transformation are healthcare (**58%**), cybersecurity (**58%**), and finance (**55%**).

1. HEALTHCARE, INCLUDING DRUG DISCOVERY AND PHARMACEUTICAL RESEARCH

The healthcare sector is engaged in a constant struggle against time. Classical computing often struggles to keep up with the demands of modern healthcare, with long runways for researching new treatments and inability to analyze patient data at scale for rapid and personalized care. With the vast processing power of quantum computing, the sector can transform detection and diagnosing, advance the creation of new drugs, and revolutionize biomedical imaging.

Biogen, an American biotechnology company, is trialing quantum to augment treatment of neurological diseases.[22] Quantum-enabled optimization, sampling and machine learning algorithms can be used to accelerate drug discovery.[23] A partner of Google Quantum AI for the past three years, Boehringer Ingelheim is another pharmaceutical company pioneering quantum computing to accelerate and optimize the healthcare sector. Their objective is to provide innovative and cutting-edge new medicines in the future.[24]

2. CYBERSECURITY

Quantum computing's impact on cybersecurity is already much-discussed. Its step up in processing power compared to classical computing will, in theory, allow for traditional encryption algorithms to be broken. This stems from traditional cryptography relying on solving complex mathematical problems; an obstacle that would take traditional computers years to solve, would take a sufficiently powerful quantum computer only minutes or hours. To tackle this problem, businesses are looking at new approaches. Technology company Cisco is one of the leaders in explor-

[22] *The Quantum Insider, The Quantum Intelligence Platform.*
[23] *Accenture, Pioneering quantum computing in R&D.*
[24] *Boehringer Ingelheim, Quantum Computing: Boehringer Ingelheim and Google Partner for Pharma R&D.*

ing a potential solution known as Quantum Key Distribution. This taps into the properties of quantum mechanics to securely exchange encryption keys between parties. Cisco even has its own research and development team that is piloting quantum computing.[25]

The risk of bad actors exploiting quantum technologies for malicious gains has drawn the attention of multiple sectors, particularly the banking sector. Banco Santander has an active programme investigating the risks posed by quantum computing to public key cryptography. In Denmark, Danske Bank is looking at the development of an ultra-secure cryptographic system based on quantum physics. And in Canada, Royal Bank of Canada has a long-running cybersecurity lab to develop cybersecurity use cases for the firm.[26]

3. FINANCE

The finance sector faces an array of complex challenges to keep up with the demands of the modern economy, many of which lie beyond the capabilities of classical computing. To that end, banks and wider financial services firms have started to invest in and scope out use cases for quantum. In the UK, Natwest is working with 1QBit algorithms and the Fujitsu Digital Annealer to drive faster decision-making on the composition of the bank's £120 billion High-Quality Liquid Assets (HQLA) portfolio.[27]

In Germany, Allianz is testing quantum computing in options valuation and quantifying operational risk. There are also plenty of growing partnerships between the sector and quantum firms. In March 2022, HSBC announced a three year collaboration with IBM to explore how quantum computers can be used for pricing and portfolio optimisation, progressing its net zero goals and identifying and addressing fraudulent activity.[28]

Atos, a global leader in digital transformation has also announced their Life Sciences Centre of Excellence with access to leading-edge technologies, such as Quantum, High Performance Computing and AI, supported by Atos' products, services and expertise in these sectors. Atos experts collaborate directly with genome and biological data research scientists to help boost Life Sciences discovery and innovation.

Whilst there is plenty of optimism and ambition for the future of quantum computing, businesses are clear-eyed in how they see the technology today. The focus today is on building application-specific use cases. **33% of businesses thought that quantum computing will only achieve application-specific usefulness.**

One such example of the application-specific quantum processor is IQM's co-design quantum simulation of nanoscale NMR. In a recent paper, IQM team demonstrate that a noisy intermediate-scale quantum computer can be used to simulate and predict nanoscale NMR resonances.[29]

The idea of building 'general purpose' quantum computers that can carry out any everyday function is promising but for this group, these longer-term ambitions are not an

[25] The Quantum Insider, The Quantum Intelligence Platform; Cisco Technologies, 'Post Quantum Security Brief'.
[26] Ibid.
[27] The Quantum Insider, The Quantum Intelligence Platform.
[28] Ibid.
[29] Algaba, Manuel G., Mario Ponce-Martinez, Carlos Munuera-Javaloy, Vicente Pina-Canelles, Manish Thapa, Bruno G. Taketani, Martin Leib, Inés de Vega, Jorge Casanova, and Hermanni Heimonen. 'Co-Design Quantum Simulation of Nanoscale NMR', 2022. https://doi.org/10.48550/ARXIV.2202.05792.

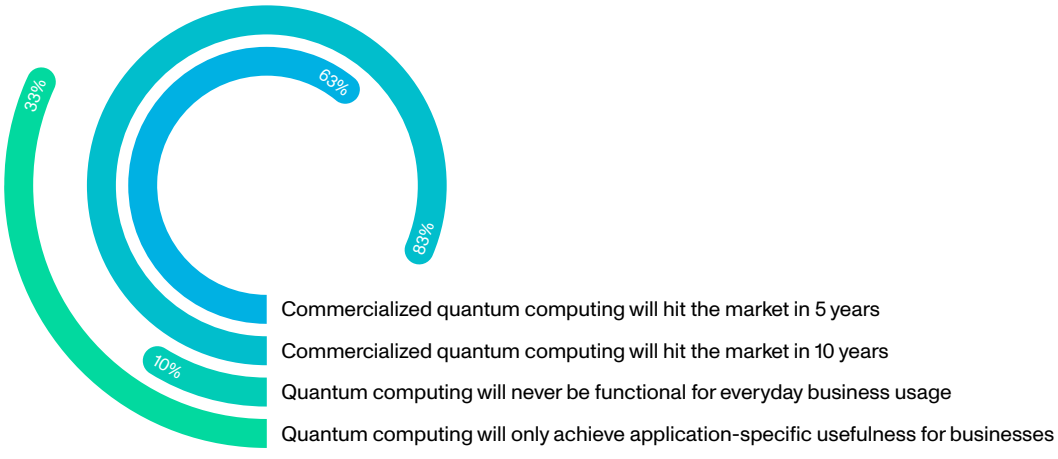
immediate priority.

But like for any disruptive technology, there are also the nah-sayers. In the case of quantum, businesses do not go so far as to reject the value of quantum computing entirely: 10% of respondents thought that quantum computing will never be functional for everyday usage. While the rest of the respondents clearly consider the implementation of quantum computing as a matter of 'when' not 'if'.

Reinforcing this, **63% believe that commercialized quantum computing will hit the market in 5 years. 90% believe that by 2030, their company's operations will have been transformed by quantum computing, and 83% predict that commercialized quantum computing will hit the market in 10 years.** Varying perceptions of the timeline for the commercialization of quantum computing can impact both businesses' current quantum investments and their speed of progression towards quantum readiness. It is worth noting that commercialized quantum computing is already happening if defined as winning big partnerships and consulting contracts, often with the support of the government. On the other hand, if we mean mature enterprise use cases relevant for many verticals and generating billions of dollars, that is where more progress needs to be made.

Similarly to the statistics surrounding the CQO and CIO leadership positions and their roles, these statistics suggest that firms have varying ideas of how quickly quantum computing will be implemented. Yet the wide majority of respondents think that, within 5 to 10 years, commercialized quantum computing will hit the market and transform our world.

> What percentage of respondents agree with the following statements?



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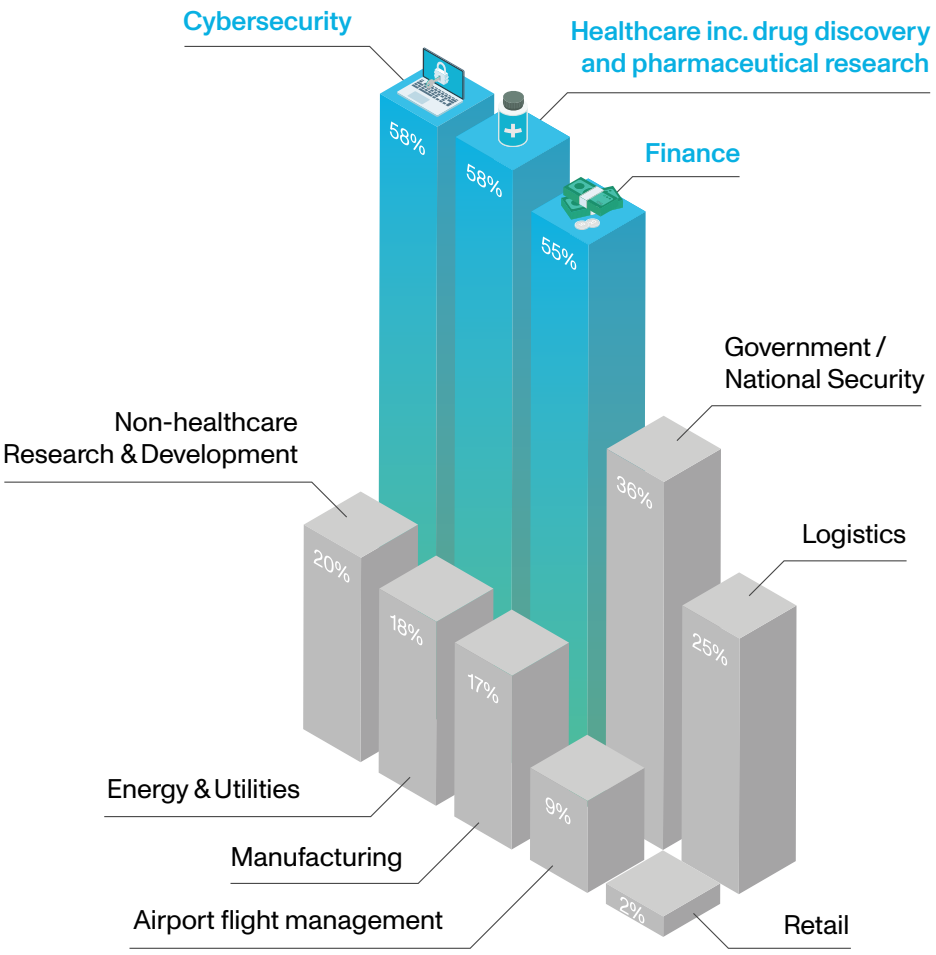
Please select the top three sectors you think will be most affected by quantum computing



State of Quantum 2022 Report - IQM Quantum Computers, Open Ocean and Lakestar (n=174)

Lakestar's View on the Quantum Software Puzzle

There is no doubt that the hardware side of quantum has already received lots of attention and investment - in fact, it is reported that 73% of quantum investments since 2018 have been in hardware startups.[30] As a multi-stage pan-European investor, Lakestar has a strong heritage and a broad portfolio of software companies. So instead we find quantum software companies currently our focus area in this emerging computing paradigm, given we have the expertise to help these emerging companies navigate go-to-market and commercial early network effects.

We fundamentally believe that in order for quantum to reach its full potential in both the short and long term, we must encourage investment and experimentation in quantum software to allow early adoption that feels naturally accretive to existing platforms and technology developed already.

QUANTUM IS NOW

Although most quantum-enabled solutions are still possibly years away, early use cases are emerging and already taking place today and already are more effective than traditional approaches. Whilst these may not necessarily be headline 'step-changes' or 10x advantages, they do however provide early signs of validation that quantum already demonstrates a distinct advantage over existing approaches as it continues to mature, which will ultimately enhance today's business models depending on the business value at stake.

While we can explore new business models that may emerge as a result of quantum, the first incarnations are likely to be iterations of existing models that are quantum-enhanced, and this is ultimately where we expect to see the first commercial use cases offering real value. Quantum offers potential solutions in the areas of optimization, simulation, and machine learning, and is well-suited to complex modeling problems ranging from drug discovery, new batteries, cryptography, new materials, and more.

One of our portfolio companies, Terra Quantum, has already demonstrated a number of early use cases and value-add for its corporate partners, demonstrating that quantum is now:

Use case 1: Workflow Scheduling Optimisation with Volkswagen Group[31]

Determining the optimal flow of tasks on an assembly line for processes such as quality inspection and paint shop optimization is highly important to maximize the productivity and utility of machines and resources. However, this is a classically intractable problem that has a high-dimensional, non-linear landscape with complex constraints.

With Volkswagen, Terra Quantum was able to use its Hybrid Quantum Algorithm to optimize this process, outperforming best-in-class classical solutions and opening a whole new window of opportunity for industrial companies across sectors.

[30] LinkedIn Pulse, Michael Spencer: Here's Why Investing in Quantum Computing Early Might be a Good Idea

[31] Pakhomchik, A. I., S. Yudin, M. R. Perelshtein, A. Alekseyenko, and S. Yarkoni. 'Solving Workflow Scheduling Problems with QUBO Modeling'. https://arxiv.org/pdf/2205.04844.pdf

Use case 2: Enhanced Image Recognition with Volkswagen Group[32]

Image recognition is one of the main use cases for machine learning. However, the huge number of parameters that must be factored in means long and expensive compute times.

With Terra Quantum's Hybrid Quantum Machine Learning and Black Box Optimisation, image recognition was able to function in the expected run times in response to the growth of search space size. Ultimately, this led to improved training for image recognition tasks, while using smaller datasets.

Use case 3: Collateral Optimisation for a Large Global Bank

Optimizing collateral is a large and extremely challenging task for global financial institutions with around $19 trillion in collateral posted on markets globally.[33] The problem of optimizing for these obligations possesses huge complexity, with the client needing to choose from combinations of many thousands of assets to meet these obligations, each of which falls into various quality standards.

For a large global bank with almost €500 billion in collateral posted, Terra Quantum's hybrid quantum solution was able to gain a funding efficiency of up to 6 basis points (bps) compared to the best existing classical solution. This provides a potential Profit & Loss impact greater than €200 million when applied across all obligations.

There are also other emerging use cases involving logistics optimization, flight planning, and much more.

MAINSTREAMING QUANTUM INTEGRATIONS

In order for these quantum-inspired use cases to be possible and accelerated, the entire software stack must be considered rather than just the hardware alone, as engineering teams will want to integrate quantum into existing platforms seamlessly.

We see this as a huge opportunity for the productization of the stack, particularly for software companies that abstract away the complexity of gate logic and instead focus on functions and procedures that are consistent with today's existing software stack while providing compatibility with today's computing paradigm. For example, an API-style quantum offering would give users API access to quantum-powered solutions without them necessarily even knowing it is quantum-powered or requiring them to be quantum engineers themselves.

We fundamentally believe that quantum will be plugged into other mainstream technologies, ahead of teams going fully native.

FULL-STACK CLOUD FOR ENTERPRISES

History has taught engineers to be wary of engaging in single hardware plays, and so there is an innate desire for engineers to be able to switch out the hardware to suit the problem at hand and flex around the price point willing to be paid for performance.

[32] Sagingalieva, Asel, Andrii Kurkin, Artem Melnikov, Daniil Kuhmistrov, Michael Perelshtein, Alexey Melnikov, Andrea Skolik, and David Von Dollen. 'Hyperparameter Optimization of Hybrid Quantum Neural Networks for Car Classification'. https://arxiv.org/pdf/2205.04878.pdf
[33] Finadium, Size of Global Collateral Market.

Our view is that quantum will be no different.

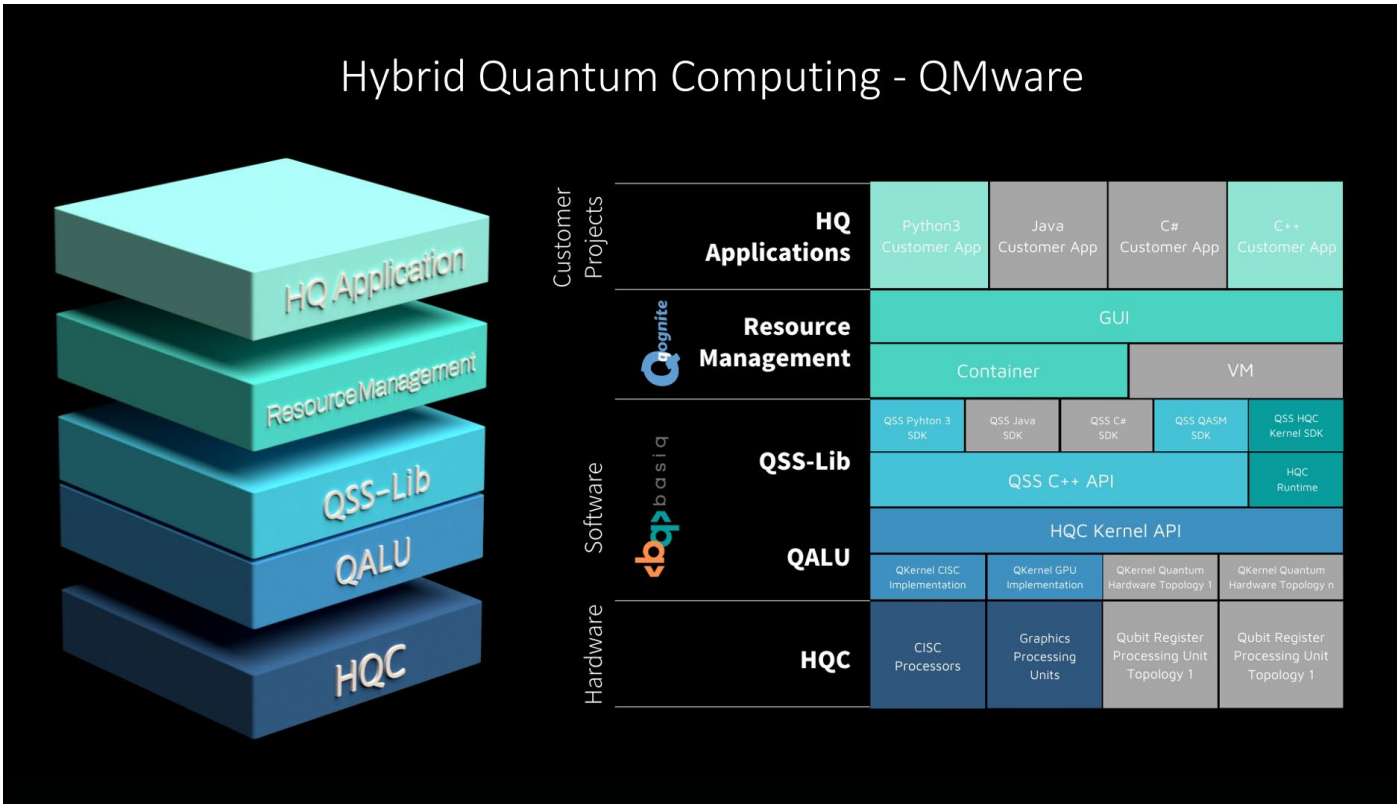
As teams experiment with these first quantum applications, they will want to write quantum code that can run across a myriad of nascent hardware as it comes online (e.g. superconducting, trapped ion, etc), which is particularly important since the first available hardware may not necessarily be the optimal choice longer-term.

Additionally, as native quantum hardware technologies are being developed, a hybrid cloud solution will be key.

This allows hybrid quantum software applications to be executed on either a combination of classical or quantum hardware, using either a “simulated qubit” or a “physical qubit” depending on the needs and technical availability at runtime.

Quantum cloud platforms such as QMware, another of our portfolio companies, is building this software stack for multi-hybrid (public or private) cloud access in a world where engineers can be hardware-agnostic.

Open quantum architecture can integrate new quantum



hardware and scale the computing performance as the hardware matures, thereby providing users with the latest and highest-performing computing power in a novel shared memory structure, covering both classical and quantum-based, while also having the flexibility to collaborate with a hardware vendor of their choice.

Private cloud implementations allow QMware's customers to also gain other benefits such as high availability, no queuing time, and an unlimited number of users leveraging up to 40 simulated error-free qubits. These private containers are set up on the highest security standards, safeguarded by European GDPR security guidelines, and implemented in a GAIA-X-compatible environment.

Stephen Nundy
Partner & CTO at Lakestar

Conclusion

This inaugural State of Quantum report has made one thing clear: quantum computing is becoming an increasing reality for business leaders around the world. With investment in quantum rising across the board, there is now a thriving and growing ecosystem of industry customers. Businesses are taking steps to investigate opportunities with the technology, backing it to achieve commercialization in the next decade with significant investment.

It is now up to firms to get that strategy right over the next decade, and beyond. As boardrooms consider the multiple opportunities with quantum computing, many will start to turn to a dedicated quantum leadership position. Indeed, our research found that 64% of business leaders we surveyed said that the CQO will become almost as or equally as important as the CIO.

This focused leadership will put businesses in a strong position to tackle some of the challenges slowing investment and adoption of the technology. The skills crisis in quantum remains a major problem for our industry: 76% of respondents agreed that the skills crisis is causing a deceleration in innovation.

Many quantum firms reading this report will no doubt have been gratified with the strong backing industry customers gave to quantum delivering a host of impactful use cases across a range of sectors, from logistics to finance, pharmaceutical to cybersecurity. 90% respondents believe that by 2030, their company's operations will have been transformed by quantum computing.

It is now up to the quantum industry to ensure the technology meets this rising interest and investment from industry customers. Several key technological issues are flagged in the research. Whilst industry customers are prioritizing investment in software development (66%), this sits alongside customers reporting that quantum hardware is currently unsustainable for their operations and sucking up significant budgets simply to run. Solving these problems will require a renewed focus on developing and advancing full-stack quantum technologies.

Whether you are a business leader interested in quantum, a quantum startup looking for guidance on industry trends, a VC looking for your next investment, or someone just interested in quantum, we hope this quantum report has inspired you to go away and rethink all that is, and will, be possible with quantum computing.

Acknowledgements

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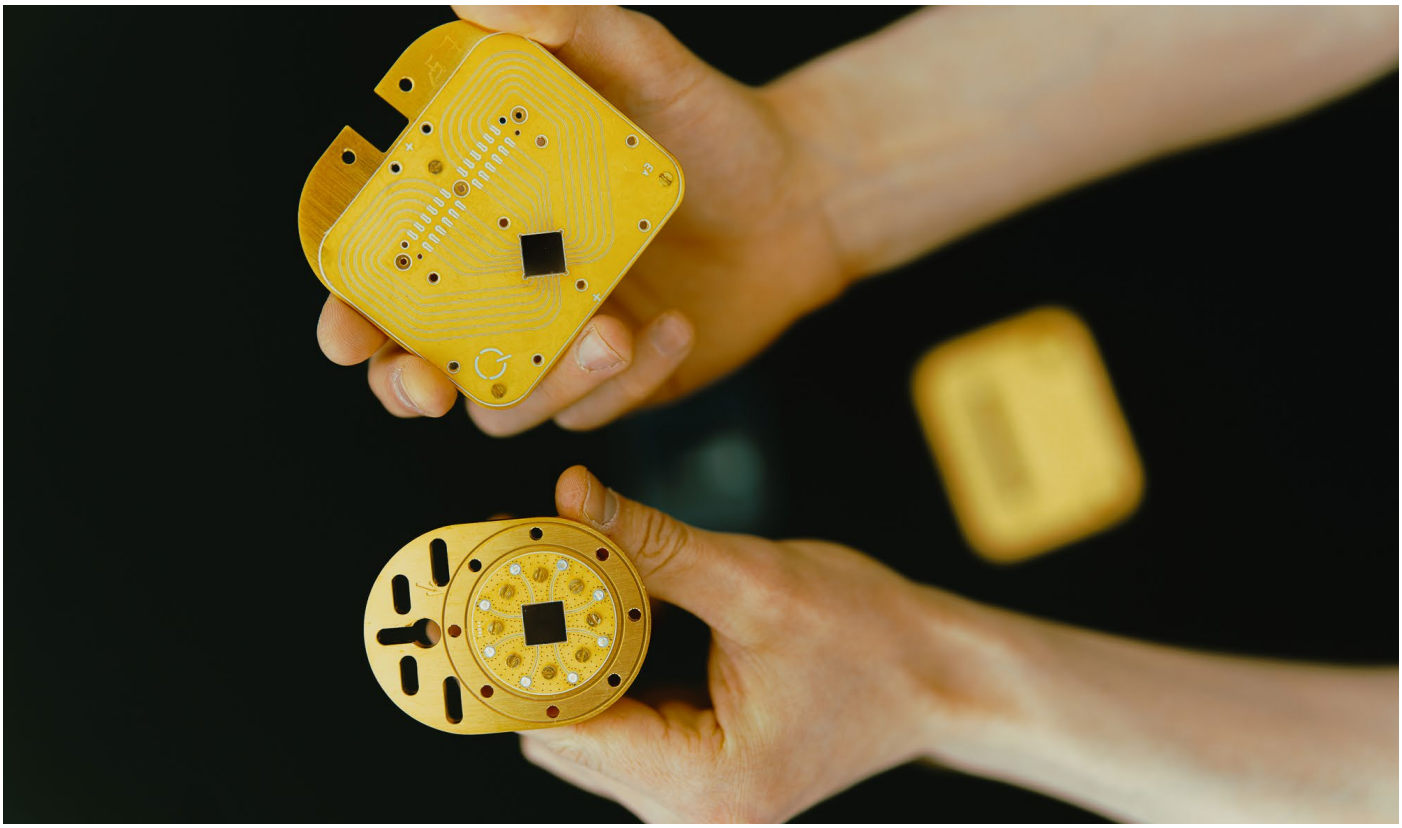
- Terra Quantum – Victoria Jodl.
- QMware – Mira Dechant.
- The Quantum Insider - Alex Challans and Evan Kubes.



Methodology and Demographics

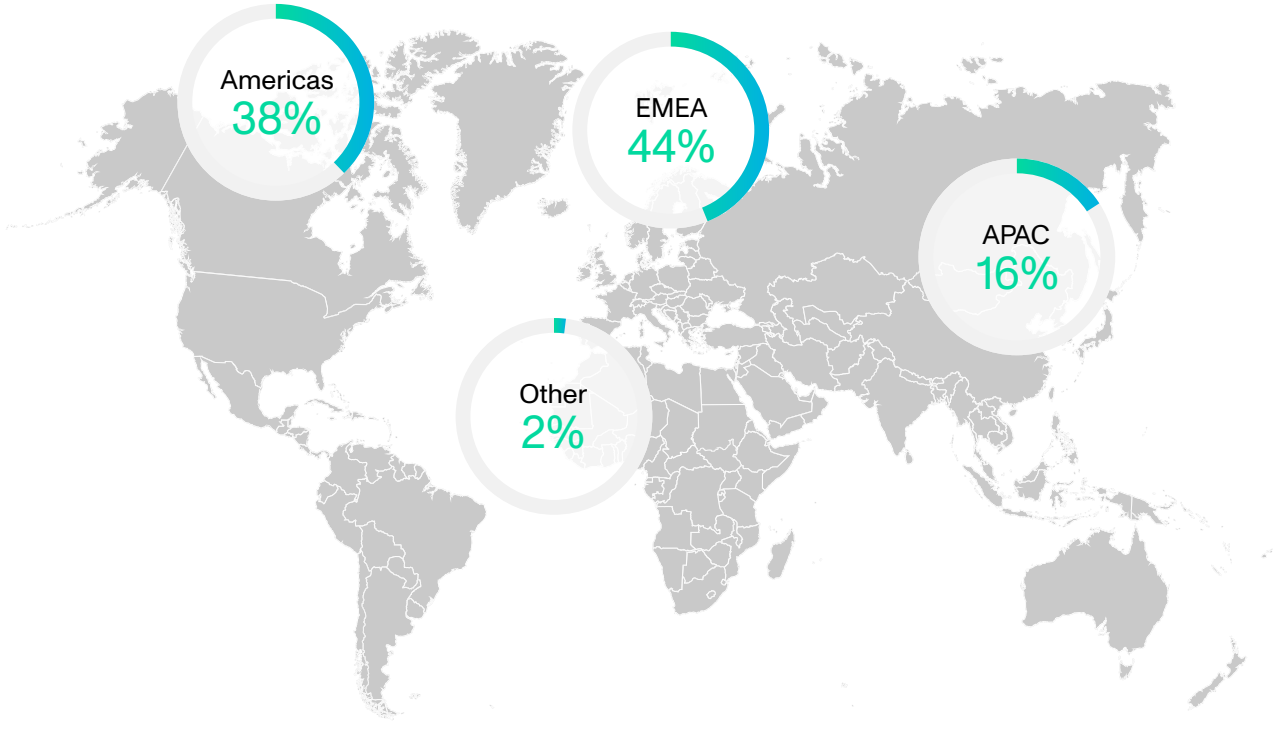
The survey was conducted between September to November 2022 through a combination of The Quantum Insider's proprietary channels and its partners. Working with a sector specialist allowed for broader distribution and ensured a set of robust, insightful answers from business leaders who are already following quantum discussions.

The total respondents ("N") was 174 and included respondents from across industry sectors and geographies.

Respondents were incentivized to complete the survey through a combination of raffle prizes and pay-per-response. The quality of answers was confirmed through including targeted screening questions, the anonymised demographic information of the respondent, time taken to complete the survey, weak text answers and through contextual review amongst other techniques.

Respondent demographic information is presented below:

In which country do you primarily work?



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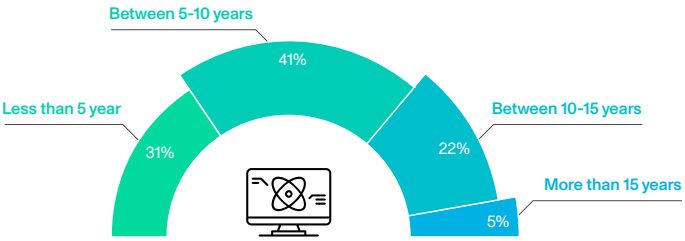
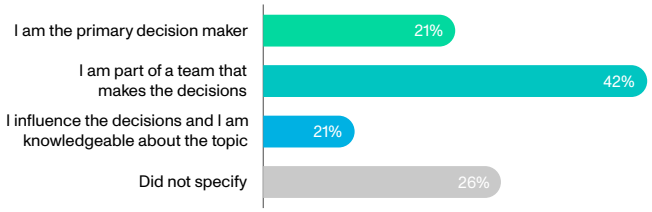
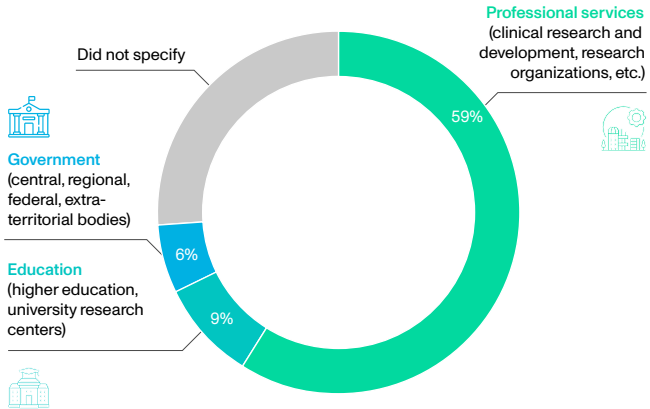
How many years of experience (Including your PhD experience) do you have in quantum computing technologies?



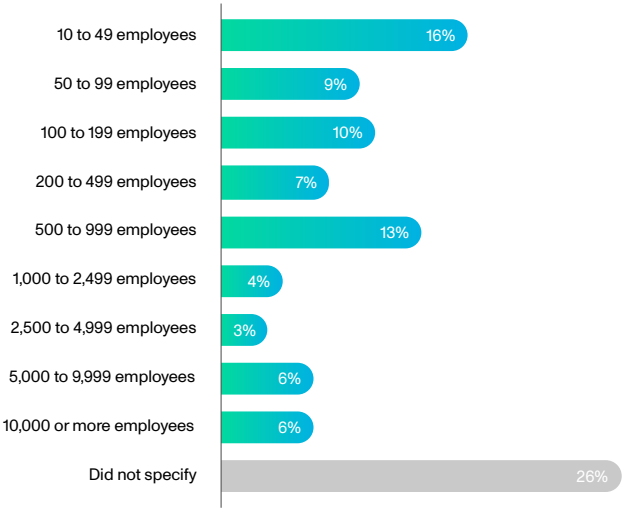
Which of the following best describes your role in using quantum technologies and in using or planning to use quantum computing technologies for your organization in your country?



Which of the following industry classifications best represents the principal business activity of your company/organization?



How many people are employed by your organization at all locations across your country?



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Contact us

ABOUT OPENOCEAN

OpenOcean is an early-stage venture capital firm investing across Europe with offices in London and Helsinki. With an entrepreneurial background from building several category-defining software businesses, we engage with founders to build and scale global companies delivering data solutions for the new economy. OpenOcean typically leads or co-leads Series A funding rounds.

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IQM QUANTUM COMPUTERS

IQM is the pan-European leader in building quantum computers. IQM provides on-premises quantum computers for supercomputing centres and research labs and offers full access to its hardware. For industrial customers, IQM delivers a quantum advantage through a unique application-specific, co-design approach. IQM is building Finland's first commercial 54-qubit quantum computer with VTT, and an IQM-led consortium (Q-Exa) is also building a quantum computer in Germany. This computer will be integrated into an HPC supercomputer to create a quantum accelerator for future scientific research. IQM has over 200 employees with offices in Paris, Madrid, Munich, and Espoo.

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ABOUT LAKESTAR

Lakestar's mission is to find, fund and grow disruptive businesses - enabled by technology - that are founded by exceptional entrepreneurs in Europe and beyond. Founded by Klaus Hommels, the team's early investments include Skype, Spotify, Facebook and Airbnb. Since raising its first fund in 2012, Lakestar manages an aggregated volume of over €1.2bn across three early stage funds and a growth fund.

The team actively advises and supports portfolio companies in marketing, recruitment, technology, product development and regulatory insight, accompanying founders from seed to early stage to growth stage or exit. Lakestar currently has the privilege of holding investments in Revolut, Blockchain.com, Opendoor, Oscar, GetYourGuide, sennder, Eigen, Public.com, SoFi, Solarisbank, Uncapped, Yapily, Terra Quantum, accuRx, Rhino, ZEBEDEE and Hometogo to name a few. Lakestar has presence in Berlin, Zurich and London.

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