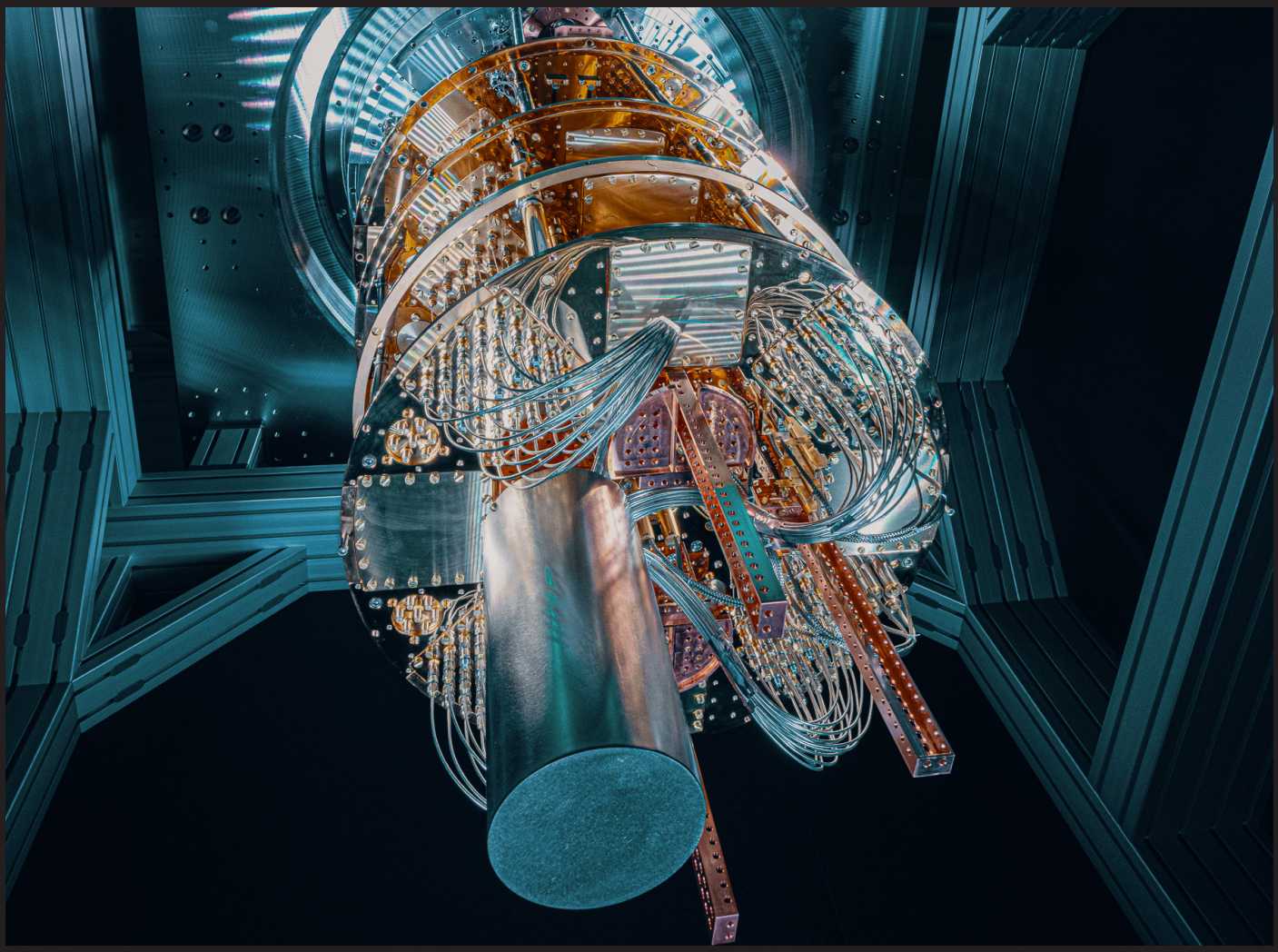
IQM OpenOcean LAKE STAR

JANUARY 2024

State of Quantum 2024

Understanding the 2023 trends and outlook for 2024



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Executive Summary

OVERVIEW

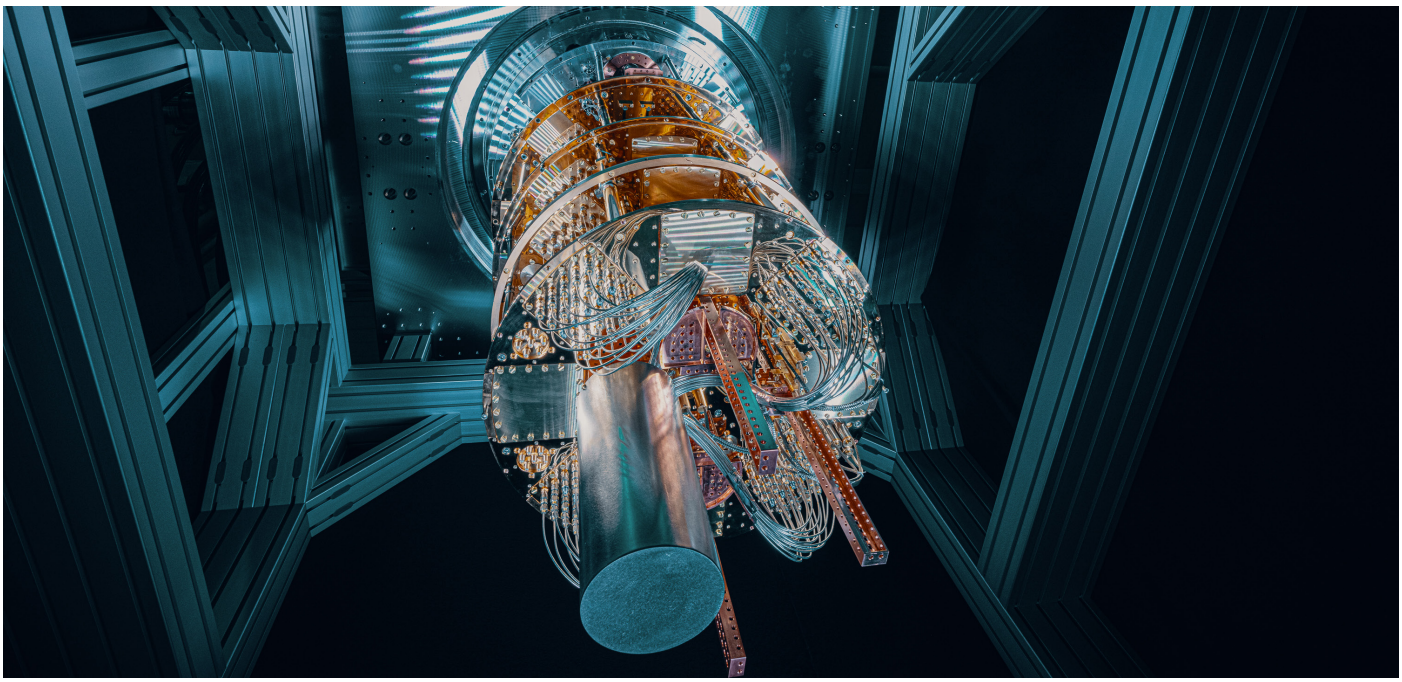
The 2024 State of Quantum report, developed by IQM Quantum Computers, OpenOcean, and Lakestar, in partnership with The Quantum Insider (TQI), is the latest research investigating the **preparedness of business leaders towards quantum technology**, analyzing sentiment across major geographies and industry sectors.

The quantum computing field is **advancing rapidly** with important breakthroughs in quantum hardware and software rendering it an **increasingly strategic asset** for organizational infrastructures who consider investing in it.

The report offers **insights on how quantum-focused firms** can bridge the existing divide between the pace and direction of quantum technological development, and the immediate **requirements from customers** to explore alternative approaches to compute.

We cover the **current status of investment trends** (probing the question: are we in a quantum winter) and investor sentiment; the delivery of operational quantum computers, both on-site and cloud-based; and the actual use of quantum computing by corporations, exploring industry-specific focus areas, introductory use cases, internal investments, as well as challenges and barriers.

The report leverages data from the quantum market, and valuable discussions with thought leaders from the industry performed in Q4 2023 (for more detailed information, please refer to the Acknowledgements).



2022 KEY TAKEAWAYS

The 2022 State of Quantum report revealed a strong interest in commercial quantum computing with over **60 percent of respondents expecting commercial applications within the next five years**. Based on these responses, we identified and predicted **dedicated roles (e.g. Chief Quantum Officer) for quantum technologies in private and public entities**, backing the exploration of quantum computing's practical applications and adoption while **addressing key skills and talent shortages**. We also identified the importance of building out the quantum software stack, with two thirds of respondents considering **software to be a main priority for quantum investment in the near future**.

Our survey confirmed that **cybersecurity, finance, and healthcare** are the sectors most likely to be most impacted by quantum computing, in some cases as a potential disruptor, others as a threat to existing systems. Business leaders anticipated multiple benefits from quantum computing, such as **solving new types of problems**, enhancing **operational efficiency**, speeding up and **resolving complex issues**, and **reducing data processing time**.

Yet, the report revealed a **potential disconnect between the immediate needs of quantum end-users** and the practical potential of the technology. Cutting through the excitement was a **concern about the costs of realistically utilizing quantum technologies**, either for research or smaller-scale use cases.

Overall, the 2022 report aimed to provide a **general sentiment on quantum technologies**. Now we are a year further on, this new report takes the logical next step and digs into **how early adopters are really exploring quantum computing's potential**.

2023/4 INSIGHTS

In 2023, quantum technologies continued their advance beyond their theoretical statements to initial practicality, seeing startups transitioning from the lab to the market whilst we also saw physical full-stack deliveries of quantum computers emerging in national labs and quantum centers.

In our report, we highlight the practical applications of quantum technologies we see today, from personalized interviews of select thought leaders' current and planned quantum activities. In the process, the report will shed light on the emergent use cases developing from this research.

Key takeaways

KEY FIGURES FOR THE QUANTUM INDUSTRY IN 2023 VS 2022

VC investments

~$1.2B

in 2023

Government commitment

>$40B

over ten years

Several new national quantum research centers demonstrating sovereign commitments to quantum

Global quantum industry private investment declined

~50%

- Americas: -80%
- APAC: -17%
- EMEA: +3%

Global technology private investment decline

~50%

x2

Enterprise end-users interested in or pursuing quantum technologies

THEME 1

No Quantum Winter, Just A Bit Colder

Venture investments in quantum technology reached a high of over $2 billion in 2022, indicating strong investor confidence in this emergent market. However, by 2023, this investment decreased by approximately 50%, prompting discussions of a “quantum winter.” In reality, industry experts refute the notion of a quantum winter, suggesting that the decline aligns with overall macro venture capital trends and does not reflect diminishing faith in quantum’s potential. If anything, the downturn in private investments has started to be increasingly picked up by government backed funding commitments and contracts, bridging the gap in investor apprehension.

Insights from experts confirm that despite reduced investment rates, the quantum industry continues to progress–although at a slower pace. A need for tempered expectations is called upon with a focus on long-term research and development, understanding that the practical applications of quantum computing could be still years away.

Quantum technology remains a niche sector, accounting for less than 1% of total VC funding. So, while the quantum technology industry is adjusting after a period of heightened investment, it is not entering stagnation, and industry insiders maintain a cautiously optimistic outlook for its future trajectory.

WHAT EXPERTS SAID

- Broad consensus that there is no ’quantum winter,’ just a deep tech market slowdown counter-balanced by government investment.
- Some interviewees echo concerns that early-stage quantum startups will struggle as they progress to series B and beyond.
- While experts’ timelines differ, quantum computing use cases that classical computing cannot handle remain potentially years away.
- Experts agree that companies should manage expectations, raise awareness, and prepare the workforce for quantum today to develop true quantum scalability.
- All experts agreed a growing sense of open knowledge and community contribution is present in the quantum industry: although more transparency and quantum roadmaps are needed to realize quantum’s full potential.

THEME 2

Availability and Advancement of Quantum Computing in Research Centers

In 2023, we saw commercial efforts by stakeholders such as IONOS and T-Systems to make quantum computing available to business customers, integrating the technology into their existing data centers. These two prominent providers have joined forces with quantum startups like QMware and PlanQK and research institutes such as Fraunhofer Fokus and the University of Stuttgart to bring quantum computing into industrial use.

As governments adopted an increasingly critical role in quantum technology, so did quantum national labs and research facilities across Europe, North America, and beyond, advancing its development from theoretical quantum research to initial practical application.

But more importantly, these new quantum research centers act as the hub for growing ecosystems in quantum technology, bringing together partnerships between public bodies, researchers, and industry.

1. **House of Quantum** in Delft is a collaborative hub for advancing quantum computing in broadening access to cryogenic quantum computing.

2. **Sherbrooke Quantum Innovation Zone** in Canada, backed by over $435 million, aims to leverage quantum technology for local manufacturing and tech businesses.

3. **The Israel Quantum Computing Center** is on track to receive a full-stack quantum computer to support research into multiple quantum types.

4. **Quantum Basel**, part of the uptownBasel campus in Switzerland, offers cloud access to IBM Quantum's platform and houses IonQ's 20 algorithmic qubits computer for advancing Industry 4.0 and the pharmaceutical sector.

5. The UK's **National Quantum Computing Center (NQCC)**, opening in 2024 aims to promote cross-sector quantum collaboration to spur growth in the UK economy.

6. **VTT Technical Research Center of Finland** has recently scaled its quantum computing resources to a 20-qubit system and announced a national strategy to reach 54 qubits by the end of 2024, focusing on micro- and nanotechnology.

7. **The Polish Poznań Supercomputing and Networking Center (PSNC)** recently received two optical quantum photonics systems from ORCA Computing to support research in biology and chemistry with machine learning.

THEME 3

Quantum and AI Show Early Potential

Artificial intelligence experienced a surge in public and corporate awareness in 2023, overshadowing quantum technologies in attention and investment. Namely, generative AI, due to its immediate impact compared to the prospective value of quantum technologies, prompted business leaders and VCs to park quantum and focus on GenAI.

Businesses were taken by surprise with AI, and have been reminded about the importance of preparing for technical disruption. As interest in AI calms, decision makers need to ensure they don't overlook quantum.

A shared sentiment is that quantum computing is not a replacement for AI or machine learning but a potential complement. Quantum could enhance AI by accelerating high-performance computing (HPC). Current AI technology may also assist in overcoming technical challenges in developing quantum computing on its path toward practical use.

The two, in combination, could open applications such as generative chemistry and digital twin simulations, with artificial intelligence to handle sequenced tasks (with ongoing adjustments) and quantum computing to be better suited for the probabilistic computations involved in these operations.

WHAT EXPERTS SAID

- Most interviewees agreed that Quantum Machine Learning should continue to be explored and highlighted the potential for AI in helping us build useful QCs.
- However, AI is cannibalizing attention, investment and interest away from quantum computing.

THEME 4

Appreciation and Understanding of Quantum Potential is Growing

Although there is a shared anticipation for quantum technologies to unlock billion-dollar values across industries, this depends on their maturation and merit over purely classical and hybrid systems.

Key challenges persist in enabling the adoption of quantum computing, such as data privacy issues through cloud access and practical algorithms to take advantage of this new paradigm of computing.

Quantum computing remains particularly promising for drug discovery, which could significantly reduce the time and cost of developing new drugs while increasing the success rate. Yet, experts caution that the journey to realizing this potential is filled with technical challenges and open questions.

In cybersecurity, the value arises from the market opportunity to thwart quantum computing's threat to existing encryption algorithms. Meanwhile, financial services could benefit from quantum computing in portfolio optimization, risk management, fraud prevention, and market simulation, with significant adoption barriers such as regulatory compliance and approval persist.

While quantum technology potential in use cases is promising, questions remain unanswered. Quantum needs to become more practical through the development of primitives and testing of real-world use cases. Considering the 'cost of useful computation' compared to classical solutions, quantum computing has a long path ahead, but its potential is worth it.

Experts agree that advancing quantum computing use cases are not a sprint but a marathon.

WHAT EXPERTS SAID

- Experts are aligned that near-term advantages could come from hybrid quantum systems, whilst industry players must realize quantum progress is not linear or predictable.
- Broad consensus that quantum chemistry and simulation, and security and cryptography are the most promising areas. Yet, regulatory compliance and practicality remain key challenges.
- While cautioning around the timing and business value, quantum computing on financial applications holds great potential.
- Universally recognized by all experts, adopting and integrating quantum technologies is more complex than just error-correction or scalability.
- Several interviewees noted useful primitives and solutions to concerns over data security / transferring sensitive information are issues that must be addressed to make quantum computing practical.
- While details differed, broad alignment that the quantum industry needs clear metrics to compare quantum performance against classical computing while articulating clear use cases for quantum computing is required for the technology to succeed.

Outlook for 2024

Going into 2024, it is clear that there continues to be a gap between current business needs and the immediate capabilities of many quantum computing systems. End users are looking for transparency in quantum computing roadmaps, and continued delivery of milestones is essential for building confidence and managing expectations.

We will also begin to witness universities launch quantum computing programs and certificates, aiming to address skill and talent shortages called on by businesses, namely in collaboration with national research centers.

Outlines of adoption barriers to quantum computing will also evolve beyond fault-tolerance and scalability into challenges such as data security and 'cost per functional computation hour' to be solved. More primitives and practical algorithms for industry players to explore quantum computation beyond theories and research questions must be implemented to realize the potential of this new paradigm of computing.

2024 will be, by exception, defined by five areas:

1. **On-Premise versus Cloud Access**: Concerns about data security and privacy regulations drive the need for on-premise quantum computing over cloud-based solutions, especially in sectors like finance, defense, and healthcare.
2. **Quantum Computing's Cost**: The high cost of quantum computing time compared to other high performance computing systems poses a barrier to widespread adoption, although industries with long R&D timelines are less deterred by short-term costs.
3. **More teams in organizations will get 'quantum ready'**: Organizations are proactively developing their teams' quantum readiness through targeted problem-solving approaches and are preparing for the eventual advancement of quantum technologies.
4. **The excited state of quantum**: Sustaining interest in quantum technology requires strategic communication and support, as quantum advantage remains a distant but significant milestone that necessitates ongoing enthusiasm and investment.
5. **Hybrid Solutions Now and Pure Quantum Computing Later**: The focus on delivering immediate value through quantum-hybrid systems reflects a strategic approach that balances current business needs with the anticipated potential of 'pure' quantum computing.

WHAT EXPERTS SAID

- Hybrid-quantum solutions are a growing pragmatic approach to leveraging quantum technologies.
- Interviewees are also concerned with the conflict between the long development timelines for quantum technologies and shareholder expectations and uncertainty of immediate business value.
- Yet, a shared recognition exists that being quantum-ready is crucial for companies to not fall behind while being cognizant of the technology being in the exploratory phase.

Forewords

IQM Quantum Computers Foreword

Dr. Jan Goetz, CEO & Co-Founder at IQM Quantum Computers

We have all heard renewed discussions about a 'quantum winter' following the economic uncertainty and cautious investments that characterized 2023. However, amidst that concern, we should recognize that the quantum community is making strong progress and that declining investments are a global phenomenon, not limited to quantum. This is what makes me optimistic. Whilst there is a long way to go, and we must remain patient, there has been no slowdown on the technological side. Change will not come overnight – but it will come in stages.

In the past year, we've seen a strong increase in the computational powers of quantum computers and examples of quantum supremacy experiments.[1] Furthermore, we have seen new and more efficient ways to implement error-correction. In these instances, quantum machines have solved calculations or run simulations that high-performance computers were practically unable to complete. With more and more companies laying out their quantum roadmaps – and following published roadmaps effectively – customers are confident about how the technology works and how it's being developed. As we make steady progress on multiple fronts, the next stage will be to create machines that can solve commercial problems at scale.

ADOPTION OF QUANTUM COMPUTING

Computing – whether classical or quantum – has always spent its infancy in the academic sector. When we look at the origins of classical computing, it all began with universities and scientific institutions seeking to solve research problems. Similarly, when Tim Berners-Lee invented the World Wide Web whilst working at CERN, it was intended to allow scientists across the world to share information automatically.[2] I expect to see quantum computing's development follow a similar path – from the laboratory to the corporate boardroom.

Today, we see a strong initial interest in quantum computing from the scientific world as technical universities seek to solve challenging scientific problems. We are committed to this development by providing an online learning platform and IQM Spark, a quantum computer productized for universities. This is compounded by the fact that many of these universities are in possession of a high-performance computing (HPC) center to benchmark against, or use in combination with, quantum computers. We are already seeing the first wave of these HPC centers purchasing commercially available quantum computers.

Indeed, early adopters of computing technology have always been those organizations working on long time scales: governments aiming to secure sovereignty or the R&D department of firms that need immense computing power, such as chemical or pharmaceutical companies. We see this trend in action with the European Commission purchasing six quantum computers for European HPC centers just this year.[3] After the first wave of scientific HPC centers investing in quantum capabilities, we will begin to see increased uptake among early adopters in government and R&D-intensive industries.

HYBRID QUANTUM COMPUTING

When we chart the progress of quantum computing over the next decade, many people imagine large-scale, fault-tolerant machines. However, in the current Noisy Intermediate-Scale Quantum (NISQ) era, we require conventional HPC systems to apply error correction. This is why hybrid quantum applications present such an excit-

[1] *Nature: IBM quantum computer passes calculation milestone*
[2] *CERN, Accelerating Science: A short history of the Web*
[3] *EuroHPC JU: One step closer to European quantum computing: The EuroHPC JU signs hosting agreements for six quantum computers*

ing opportunity. Users can outsource very complex tasks to a quantum computer while using conventional HPC to handle the data processing. In the future, such a hybrid approach could also be the way to implement large-scale error correction. We're currently working with the VTT Technical Research Center in Finland to combine its quantum computer with LUMI, Europe's most powerful computer, with remote connections such as this representing a promising future for hybrid quantum applications.

We see this use case for hybrid quantum computing in another key adoption sector: data centers. These centers have two types of problems to solve: the first are problems involving huge quantities of data, such as processing high-frequency trading data to inform investment decisions. The other type of use case is very complex computing problems, such as molecular modeling for drug discovery or logistical optimization for flight paths. The latter is where quantum machines can shine, whereas the former is best suited for classical HPC methods, so we are focusing our HPC integration efforts on reflecting this development.

Mainstream quantum adoption will be a smooth process but not an instant, black-and-white transition. We will progess from scientific problem-solving to R&D processes, such as discovering new drugs, and from these industry use cases into mainstream problems, like portfolio optimization. This is why we're working with businesses, HPC centers, data centers, and governments to provide them a pathway to quantum advantage through our new IQM Radiance system, taking them from a 54-qubit system to a 150-qubit machine in the near future.

THE TALENT LANDSCAPE

Another silver lining to 2023 was the evolving talent landscape and the arrival of Generation Z experts into the quantum computing industry. Five years ago, the quantum computing field was dominated by quantum physics professors at universities, but that is changing. We're now seeing professionals from non-quantum domains like electrical engineering and computer science contributing their invaluable experience designing large-scale classical computers to the quantum industry.

While quantum physicists remain the primary talent base for quantum startups, the influx of process engineers, electrical engineers, software developers, and other professionals in adjacent industries adds credibility to the field and brings us closer to a fully-functioning quantum computer. However, with a changing talent base comes new challenges for leaders. Effective management and mentoring across generations will be necessary to allow both new perspectives and hard-won wisdom to guide the field forward responsibly.

LEVELING THE PLAYING FIELD

While we see promising signs for quantum development, many quantum startups still find it difficult to scale without support from governments and private investors. In order to enable the kind of fast growth we've seen in areas like AI, closer collaboration between government, private business, and other sources of funding is needed, especially in Europe. Awareness is a major obstacle for us to overcome in this space: for example, proving to stakeholders at technical universities how spin-off equity can drive success for the organization as a whole.

While we must remain patient, I am optimistic about continued progress in quantum computing through 2024 and beyond. With increased collaboration between public and private capital, a growing talent pool from diverse technical backgrounds, and responsible leadership, we are making encouraging progress towards broad-based quantum adoption.

OpenOcean Foreword

OpenOcean

Ekaterina Almasque, General Partner at OpenOcean
Ollie Sellers, Senior Associate Data Scientist at OpenOcean

Quantum computing has made great strides in the last few years, as evidenced by Google scientists using a 70-qubit Sycamore machine to make calculations instantly that would have taken classical supercomputers 47 years.[4] However, investment in quantum has not been spread equally across the ecosystem. Last year, 66% of businesses we surveyed considered software development to be a main priority for quantum investment.[5] While we have seen quantum software companies experience some success through 2023, such as Q-CTRL closing a Series B funding round at $54 million or early-stage firm Algorithmiq raising $15 million for its Series A funding round, data reveals that VC investment in quantum computing startups from 2021-22 brought in only $98m for quantum software, compared to $362m for computers and processors.[6]

If we are to successfully commercialize quantum computing, we cannot neglect quantum software. Investment in the quantum ecosystem is focusing far too heavily on the hardware layer and not enough on building out the software and middleware to build full-stack solutions. In our previous report, we encouraged organizations to start thinking strategically about how they will operate in the quantum era – understanding how quantum software can and will be integrated into their existing stack. Without that understanding and investment into software, this missing layer will continue to hold us back from broad quantum adoption.

To fully realize the potential of quantum computing, investors have a once-in-a-lifetime opportunity to guide quantum startups in strategic areas of the ecosystem and contribute to quantum's strategic global growth. Profiting from this new paradigm of compute will require us to replicate the success of far-seeing investors in companies like Intel, Arm, and Nvidia. Achieving the multi-billion-dollar quantum companies of the future requires investors to focus their attention on building the nascent layers of the full quantum technology stack. We must ensure that we build the hardware, software, user interfaces, and human layers to work together as efficiently as possible.

BUILDING GLOBAL QUANTUM COMPANIES

Several corporate giants with a global presence have made quantum investments in 2023. This includes Microsoft launching the Azure Quantum Elements platform to accelerate scientific discovery by combining quantum, AI, and high-performance computing, and IBM unveiling 'Quantum Heron', a next-generation quantum processor.[7]

However, the tech giants are not the only place where quantum innovation can develop. It is startups – not established corporations – that have historically built the most disruptive solutions. There is an opportunity in the market to build truly international quantum companies: businesses with customers, investors, and partners on every continent. Although 2022 saw investors commit $2.35 billion to quantum technology startups, these startups often have a regional customer base and physical presence.[8] In order to take these startups to the next stage, we must commit for the long term and think in time scales measuring in years and decades, not weeks and months.

[4] *Arxiv - Cornell University: Phase Transition in Random Circuit Sampling, and The Telegraph: Supercomputer Makes Calculations in Blink of an Eye That Take Rivals 47 Years*
[5] *IQM: State of Quantum 2022 Report*
[6] *Dealroom: The European Deep Tech Report 2023*
[7] *TechCrunch: Microsoft expects to build a quantum supercomputer within 10 years, and IBM Newsroom: IBM Debuts Next-Generation Quantum Processor & IBM Quantum System Two, Extends Roadmap to Advance Era of Quantum Utility*
[8] *McKinsey Digital: Quantum technology sees record investments, progress on talent gap*

To better understand the quantum investment landscape, we should examine the previous paradigms of compute. From the launch of Intel's 8086 processor in 1981, Intel processors and the x86 architecture dominated data centers for decades. With the increasing use of mobile devices came Arm and new battery-efficient, reduced compute chips. Then, Nvidia rose to prominence with the need for highly parallelized Graphics Processing Units (GPUs) to handle the exponential growth of AI workloads. These successive shifts show how a single technology advancement can overturn the entire industry - as long as the software and hardware are co-designed for maximum efficiency.

Take Nvidia as an example. As a private firm, it didn't raise a huge amount of capital – but it then went on to raise $4 billion following its IPO. Before its IPO, GPUs were seen as primarily for gaming and graphics and AI was not a key focus area for Nvidia. Many private market investors missed out on Nvidia and high-potential returns because they didn't believe in AI's potential to alter the paradigm.

Quantum computing will be a rapid paradigm shift – and investors who don't invest now may not have the chance later. We can already see how the market is starting to transition into rapid commercial growth when we look at companies like IonQ, Rigetti, and Pasqal. In November 2023, IonQ announced it had reached its target of $100m in revenue, including Q3 revenue growth of 122% on the previous year, a whole quarter ahead of target.[9] The multinational quantum corporations of the future are being founded today. So, what is holding investors back?

BARRIERS TO PRIVATE CAPITAL INVESTMENT

Private investment in quantum at both the early and mature stages is resilient when compared to the overall investment landscape. The Quantum Insider (TQI)'s data demonstrates that venture capital investment into quantum technology is in line with the broader venture capital market, at an approximate 50% decline in 2023 versus 2022.

However, data from our internal investment platform, Sampo, also reveals that many investors who have traditionally invested heavily in hardware technologies are reluctant to support quantum computing to the same degree. Sampo data has shown that, while there is no significant difference in average fund size between hardware and quantum computing investors, there are more than 5 times as many investors in hardware than in quantum. This suggests that the quantum ecosystem, across all layers of the stack, is lacking a diverse pool of potential investors.

Some investors are cautious around quantum computing today in part due to a lack of clear understanding about how it will deliver value for end users. Most use cases today focus on benchmarking results against classical computing methods. However, we're not yet at the stage where quantum advantage is directly translatable into commercial use cases.

Some major players in quantum feel we must move beyond the NISQ or ASIC quantum era, and are instead directing their resources into pushing towards full, error-corrected machines However, we believe there is value to be accrued along the way with more application-specific devices – a development that will be driven by innovative startups striving towards more efficient design.

Catalyzing more private investment means demonstrating tangible use cases with clear commercial potential. This means actively partnering with enterprise end users across sectors like finance, energy, materials science,

[9] *Inside Quantum Technology News: IonQ hits $100 million in bookings, Rigetti revenue grows as commercial quantum market revs up*

and healthcare. By co-developing quantum solutions for domain-specific problems together with corporate clients, quantum startups can better understand commercial needs and design hardware/software accordingly.

To make quantum machines a reality in the short to medium-term, we must change the rules of the game. We must focus on application-specific machines with more intelligent architectures. This will enable us to gain value from a smaller number of high-fidelity qubits, making use of quantum machines that are more feasible for a wide variety of applications, such as IQM Spark, a 5-qubit superconducting quantum computer, professionally designed and calibrated as a turnkey solution.

REASONS FOR OPTIMISM

However, there's no cause for pessimism. Achieving functional quantum computing and widespread adoption may be a challenge, but it's a challenge with well-defined parameters. At its heart, it is a clearly articulated engineering problem. Quantum is a realistic goal if we invest wisely and strategically.

We have the chance to establish several multi-billion – and due to the number of industries such as pharmaceutical research that quantum could turn on their heads, potentially even trillion-dollar – companies that will reign over the software industry in the same way Nvidia currently leads in AI hardware. But to achieve this, we need to ensure that each layer of the quantum stack is co-developed and designed to work in harmony.

As the industry seeks to construct a fully-functioning software stack, the experts we interviewed this year agreed that there is a growing focus on open knowledge, community contribution, and education in the quantum industry. For example, Fabio Sanches, Quantum Computing Director at the Federal Reserve, emphasized that many organizations would feel uncomfortable accessing quantum through the cloud due to data security concerns. So, this highlights the need for more startups focusing on clear governance protocols for remote access use cases and transparent data storage practices.

Quantum algorithmic development is crucial, but the hardware and foundational level of software need to be developed in tandem, mirroring how Intel co-developed x86 assembly with its hardware, or how Nvidia designed CUDA kernels to run code on its GPUs. We must focus on building scalable and programmable Quantum Processing Units (QPUs) – a task that companies like IQM are likely to lead in years to come.

However, alongside these tangible developments, there's another layer that needs attention to fully realize quantum computing's potential – the human layer. We have an opportunity to overhaul our education systems: preparing for the quantum era requires the next generation to start thinking in quantum terms. A generation that grew up in the era of classical computing will need to adapt and learn how to operate and code quantum machines. Indeed, this is already happening. 2022 saw an increase of 72% in the number of universities with formal master's programs in quantum technologies.[10]

Imagine a world where schoolchildren learn about the principles of superposition alongside theories of gravity or light. They'll gain an understanding of the physical principles set to shape their lives for decades to come.

[10] *McKinsey Digital: Quantum technology sees record investments, progress on talent gap*

Lakestar Foreword

Stephen Nundy, Investment Partner & Chief Technology Officer at Lakestar
Christina Franzeskides, VC Investor at Lakestar

In the inaugural State of Quantum 2022 report, we emphasized the necessity of a hybrid cloud solution to abstract away hardware limitations. The ensuing months have validated that claim. However, not every development in this field could be so easily predicted.

Since the release of last year's report, we have witnessed a year of growing and profound geopolitical and economic uncertainty. Yet, amidst this uncertainty, the past 12 months have shown an encouraging surge of public sector investment into "Deep Tech". This investment has aided the development of innovative technologies such as quantum and generative AI. Examples such as the EuroHPC Joint Undertaking and UK National Quantum Strategy illustrate this dynamic.

To successfully build on these endeavors, it is essential to understand how quantum affects and is affected by the wider ecosystem. This will be critical to extracting maximum advantage from the quantum revolution for a range of stakeholders. These include corporations planning their strategic roadmap, investors assessing their portfolio makeup, and policymakers drafting laws to cover the next wave of innovation and technological discovery.

GOVERNMENT LEADERSHIP

A major development in 2023 has been the rise of governments as the primary early purchasers of quantum technologies, ahead of corporations, interestingly. The Quantum Insider's (TQI) data showcases the significant scale of this trend. If conservatively spread over 10 years ($4bn-$5bn yearly), government funding for quantum is twice the peak of VC investment in 2022.

Governments are backing quantum as a national strategic imperative. In an increasingly uncertain geopolitical environment, governments are recognizing the capabilities quantum technologies offer across a range of areas from security to optimization of infrastructure. TQI's market monitoring showed that more than 30 governments are actively involved in quantum technologies. Notably, two thirds of these governments have formulated a formal coordinated policy on quantum.

This coordinated action from governments has marshaled investment and given R&D efforts a clear roadmap to follow. Governments have an important convening power, bringing together investors, start-ups, and other key stakeholders to develop policies and incentives to ensure the continued growth of the quantum ecosystem.

European governments are well positioned in this area. Exciting quantum startup ecosystems are growing up across Europe, centered in innovation hubs such as Munich, Paris, the Golden Triangle in the UK, the Netherlands, and Finland. These grassroots communities exhibit the key ingredients needed for major quantum breakthroughs - exceptional talent, academic excellence, access to capital, and government support.

However, these European hubs require continued maturation and development to match the scale and commercial viability of quantum clusters in the US and China. In the EMEA and APAC regions, investment is being driven by governments seeking to establish local quantum capabilities as 'critical infrastructure' needed to uphold technological sovereignty and independence, particularly as quantum computing moves towards real-world applications.

SOVEREIGNTY AND SECURITY

As countries face growing cyber threats on Critical National Infrastructure (CNI), investing in long-term quantum security measures will be essential to securing sovereignty.

The World Economic Forum has reported that governmental, business, and individual cybersecurity measures are increasingly being rendered obsolete by sophisticated and frequent cybercrimes.[11] Indeed, the UK Government's 2023 Cyber Security Breaches Survey identified approximately £2.39 million instances of cybercrime across all UK businesses.[12] In this context, there has been surprisingly little discussion about how quantum will help us combat these threats at a time when data harvesting, for decryption later, is well understood.

Quantum security presents an opportunity to protect data "once and for all". Through Quantum Key Distribution (QKD), parties can encrypt communications by securely sharing secret keys at high speeds and over long distances. Additionally Quantum Random Number Generators (QRNG) allow users to use quantum mechanical phenomena to generate true randomness for encryption keys or authentication protocols.

Startups such as Terra Quantum are already using these quantum technologies to build proven quantum-safe encryption standards. In June, Terra Quantum shattered previous world records for quantum key distribution (QKD) by reaching a transmission rate of 34 bits per second (previously 0.0034) over a distance of 1,032 kilometers. These breakthroughs will help national governments and large corporations to keep pace with evolving cyber threats, establish boundaries and exert control over their networks, while securing national sovereignty.

QUANTUM AND GENERATIVE AI

One of the biggest topics of discussion in technology over the past year has been the rise of Generative AI. Funding, innovation, and attention have focused on LLM companies like OpenAI, Anthropic, Mistral, and Aleph Alpha for good reason. The immediately demonstrable nature of GenAI has excited the weekend hacker, enterprise engineers and non-coding population alike, with its easy to access manifestations seemingly popping up everywhere.

Quantum on the other hand, by the nature of it, is difficult to grasp conceptually and has always felt distant. This is despite announcements by industry giants such as IBM unveiling a 1000 qubit machine being online and the emergence of hybrid quantum as a paradigm to bridge the gap between "now and then". As a result, quantum has been pushed into the shadow of GenAI this last year as teams focus on the "here and now".

However, quantum computing and artificial intelligence are not separate discussions. If we fail to consider the long-term potential emerging from the intersection of the two, we risk overlooking a valuable opportunity to match the high-performance computing (HPC) capabilities of quantum with the needs of AI. This combination promises to be a driving force for future advancements in both fields - especially in regard to developing Artificial General Intelligence (AGI).

Quantum computers, with their unparalleled exponential computational capabilities, promise to process vast amounts of data and perform complex calculations at speeds far beyond those of traditional computers. Consequently, quantum computers are uniquely suited to bolster advancements in AI, particularly with machine learning requiring the rapid processing of increasingly large datasets, as well as the growing number of variables and constraints associated. We have already seen companies and national research laboratories combine quantum and AI. Building on their successful development of Japan's first

[11] *World Economic Forum: Global Risks Report 2023*
[12] *UK Department for Science, Innovation & Technology: Cyber security breaches survey 2023*

superconducting quantum computer to perform quantum chemistry calculations, Fujitsu and RIKEN have created a new drug discovery technology using generative AI to predict structural changes of proteins from electron microscope images.[13]

These breakthroughs aren't limited to incremental improvements to existing systems. They have the potential to pave the path towards AGI, the apex of AI's evolution. This means the ability to understand, learn, and apply knowledge across a wide range of tasks at a level equal to or beyond human capabilities.

However, reaching that point requires business leaders to plan their deployment on a realistic schedule. To take advantage of the varying pace of commercially available qubits, we must be hardware agnostic. With quantum cloud companies like QMware building this software stack for multi-hybrid (public or private) cloud access, businesses will be able to provide engineers with the latest and highest-performing computing power whilst having the flexibility to collaborate with a hardware vendor of their choice.

CONCLUSION

In the long term, quantum will be a strategic organizational capability on par with the cloud in terms of impact and necessity. However, the patient capital and nurturing environment required for this progress demands substantial government participation. In this respect, governments will play a crucial role in supporting the development of national quantum capabilities as they seek to build a sovereign quantum strategy.

Governments must catalyze growth by fostering quantum ecosystems, anchoring homegrown talent, and enabling domestic startups to access the growth capital they need. If nations facilitate the flow of knowledge, capital, and talent, this will lead to quantum innovation in hardware, software, and algorithms. To make progress, we must collaborate more. We should be pooling brain power across academic, corporate, and state institutions - sharing use cases, positive and negative experiences, and embarking on the quantum revolution together.

Given the rapid maturation of quantum machines, hybrid architecture will allow business leaders to seamlessly integrate diverse quantum hardware. For these initiatives to succeed, users must be able to scale computing performance with the hardware available.

It will be thrilling to watch where the next generation of leading quantum startups emerge from and the partnerships they will develop.

[13] *FUJITSU: Fujitsu and RIKEN develop AI drug discovery technology utilizing generative AI to predict structural changes in proteins and Fujitsu and RIKEN develop superconducting quantum computer at the RIKEN RQC-Fujitsu Collaboration Center, paving the way for platform for hybrid quantum computing*

2023 quantum market updates

The quantum technology landscape of 2023 was a pivotal year of academic achievements, commercial endeavors, financial investments and government strategies—all converging to accelerate the transition of quantum from theoretical exploration to potential practical application and the end goal of quantum advantage. The industry witnessed significant milestones that not only demonstrated technical advancements but also set a foundational structure for quantum computing's future.

The below represents a quick snapshot of some of the key quantum market updates which will–by nature–be non-exhaustive.

ACADEMIC ADVANCES IN PRACTICAL QUANTUM COMPUTING

In research, a Harvard-led team of scientists, which included significant support from QuEra researchers, successfully executed large-scale algorithms on an error-corrected quantum computer with 48 logical qubits and hundreds of entangling logical operations. As error correction is a critical hurdle for practical quantum computing, scientific thought leader Scott Aaronson called the experiment "plausibly the top experimental quantum computing advance of 2023" and added it moved timelines for quantum fault tolerance forward. Topological quantum computing saw an increase of interest, as well. Scientists from Quantinuum, a joint venture between Honeywell Quantum Solutions and Cambridge Quantum Computing, made headway by successfully creating and manipulating non–Abelian anyons—quantum states that could potentially enable fault-tolerant quantum computing. This impressive advance provides a robust pathway towards scalable quantum computation. Researchers at Rice University furthered the understanding of topological states by demonstrating their entanglement with other quantum states, a discovery that could lead to new ways of storing, scaling and processing quantum information.

The academic progress dovetailed with commercial strides, as industry players advanced the development and accessibility of quantum computing. IQM Quantum Computers, a European quantum computing company, unveiled IQM Radiance™, an upgradable quantum computing platform designed for businesses, high performance computing centers, data centers and governments that comes in 54- and 150-qubit variants and "IQM Spark," a superconducting quantum computer designed to provide tailored learning experiences for academic institutions and research labs. This initiative is poised to nurture a new generation of quantum computing expertise. Meanwhile, IBM revealed that their experiments in error mitigation on superconducting quantum processors may be a critical step towards practical quantum computing—a long-standing hurdle in the field. In December, IBM unveiled IBM Condor, a 1,121 superconducting qubit quantum processor and the Heron processor, noted as offering new levels in stability and performance.

Scientists also made strides in 2023 to develop and test technology that will underpin future ultra-secure quantum networks. For example, Terra Quantum set a record for securing long-distance communications with quantum encryption, sending quantum-secure communication on optical-fiber cables over 1,032 kilometers.

COLLABORATIONS AND EXPANSION

The year also marked collaborations and expansions in the quantum computing sector. IonQ, a provider of trapped-ion quantum computing, and Hyundai Motors publicized the expansion of their partnership, which is focused on harnessing quantum computing for automotive innovation—a move that could revolutionize how we understand and build vehicles. In Finland, VTT Technical Research Center and IQM completed the country's second quantum computer, boasting a 20-qubit system that reaffirms Finland's position as a frontrunner in quantum technology. Furthermore, the OpenSuperQ Project, a collaborative international effort, embarked on the ambitious goal of constructing an open superconducting quantum computer, potentially democratizing access to quantum resources.

In addition to the efforts to make quantum computing broadly accessible to business and industry, large corporations are beginning to deepen their embrace of quantum and companies within the quantum industry. NVIDIA, a leader more associated with classical and supercomputing, announced numerous partnerships with quantum vendors, including, for example, QMware and Terra Quantum. In the first deal, QMware has integrated NVIDIA's DGX quantum-classical stack into its quantum-hybrid platform QMware Cloud, advancing its capabilities.[14] Terra Quantum also partnered with NVIDIA in 2023, to enhance data analytics across various industries using a hybrid quantum computing approach.[15] Similar to the QMware partnership, Terra Quantum also has integrated quantum algorithms with NVIDIA's GPU computing platform, facilitating advanced machine learning and simulation. Working with Quantum Machines, NVIDIA also announced new architecture for researchers working in high-performance and low-latency quantum-classical computing.

Canada also positioned itself as a quantum hub with the launch of DistriQ, a quantum innovation zone. This project, a collaborative effort among Quantonation Ventures, ACET, and others, exemplifies the growing global commitment to fostering quantum ecosystems that encourage innovation and commercialization.

[14] *Switzerland Global Enterprise: QMware Collaborates With NVIDIA on Cloud Offering*
[15] *Terra Quantum: Terra Quantum Aims to Unlock Unprecedented Business Performance with Hybrid Quantum Computing in Collaboration with NVIDIA*

CAPITAL MARKET PULLBACK

Funding rounds entered 2023 strongly, but reflecting the general sluggishness of venture investing in general, began to trail off by mid-summer. However, several companies secured substantial investments to fuel their growth. As part of a growing partnership with Microsoft, Canadian-based Photonic Inc. raised $100 million in a round led by BCI and Microsoft. PASQAL, a French company specializing in neutral atoms quantum computing, completed a Series B funding round of €100 million. This investment, led by Temasek and supported by a consortium of new and existing investors, will support PASQAL in its next phase of its expansion. Q-CTRL, a quantum software company, welcomed Morpheus Ventures as a new investor in its Series B funding round, which amassed $54 million. Additionally, Quantum Motion, a UK-based quantum computing scale-up, raised over £42 million in equity funding, with Robert Bosch Venture Capital and Porsche SE leading the charge.

Whereas multiple quantum startups selected the special purpose acquisition company, or SPAC, as a pathway to public listing – including IonQ, Rigetti, and D-Wave – in prior years, in 2023 only one significant quantum SPAC was announced. Zapata AI, which has pivoted from a quantum software company to a generative AI company, announced in late 2023 that it would become a publicly traded company through a SPAC. It should also be noted, several companies that chose the SPAC route suffered stock reversals during 2023, including Rigetti and D-Wave, which were both threatened with de-listing on the NASDAQ exchange when their stocks traded under a dollar for an extended period. We discuss the investment landscape in detail later.

The picture changes when focusing on IonQ, a US-based quantum hardware and software vendor. Following its Q3 results, IonQ announced over $100 million in bookings, one of which is delivering two quantum computers to the US Air Force Research Lab (AFRL).[16] The quantum company's newest quantum computer, IonQ Forte, joined IonQ's existing quantum portfolio of IonQ Harmony and IonQ Aria on the AWS platform: Amazon Braket Direct.[17] The Forte quantum computer is considered one of the most powerful quantum computers commercially available to date.

By late 2023, analysts did note a new wave of private funds entering back into quantum, signaling a possible restoration of venture funding for the industry. Oxford Quantum Circuits, for example, announced a $100 million Series B in late November 2023. The round was led by one of the leading Japanese venture capital firms, SBI Investment, however even here we saw significant implicit government backing from - for example - British Patient Capital. We provide a deeper dive into the 2023 quantum technology funding rounds later in this report.

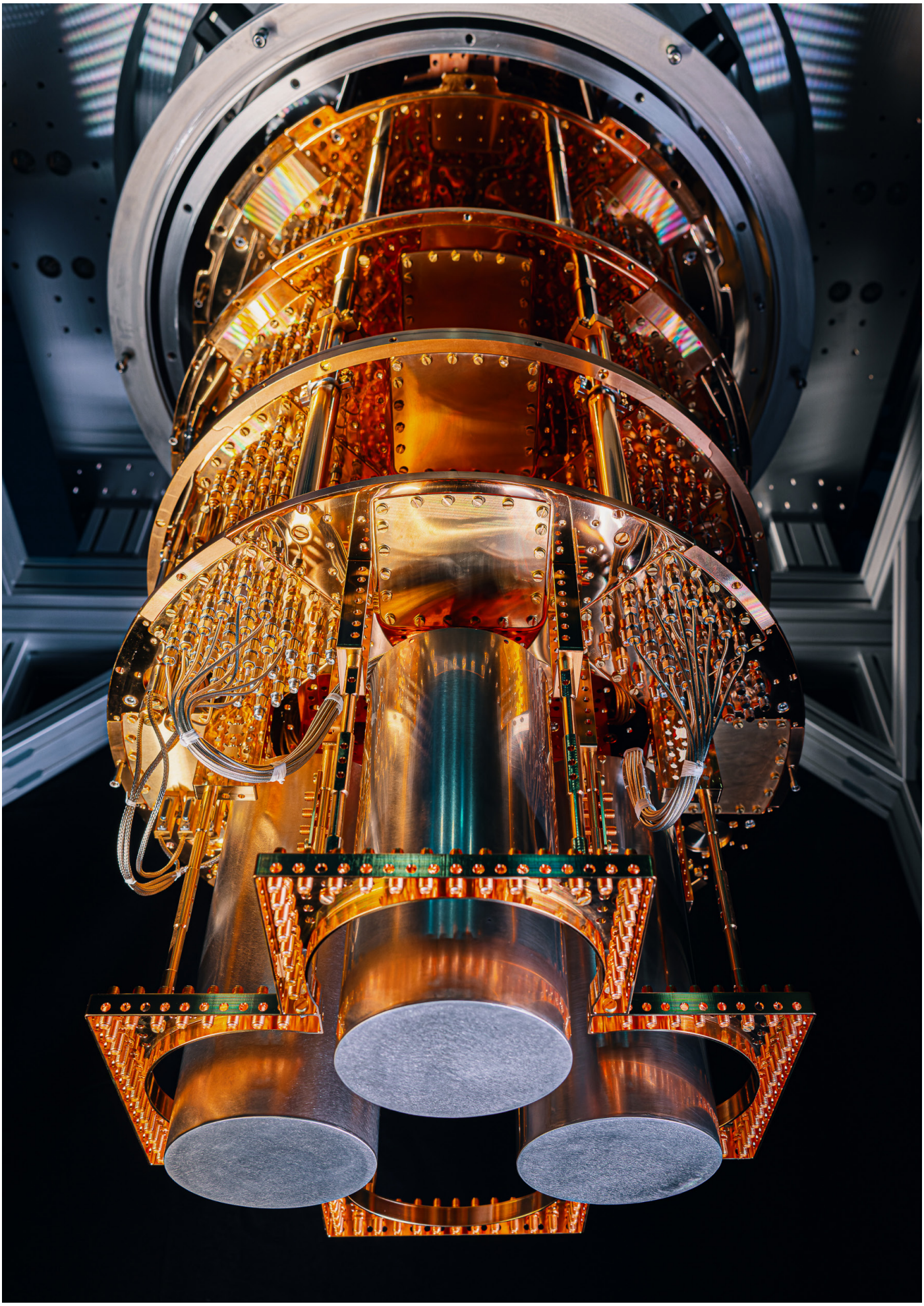
[16] *Quantum Business News: IonQ Hits $100M in Revenue, Targets Quantum Advantage*
[17] *IonQ Investor News: IonQ's Most Powerful Quantum System, IonQ Forte, Now Available through the Amazon Braket Direct Program*

GOVERNMENT FUNDING PROVIDES AN IMPORTANT BACKBONE

While interest from private sources showed signs of slowing in 2023, governments across the globe doubled down on quantum tech, recognizing the importance of the technology to national security, defense and privacy. The UK and South Korea laid out strategic plans underscoring their commitment to quantum technologies. The UK government, through its National Quantum Strategy, identified quantum technologies as a key driver for the country's future economic, social, and environmental prosperity. South Korea announced a substantial investment of over 3 trillion won (~$2.3 billion), aiming to establish itself as a quantum leader. These national strategies indicate a recognition of the critical importance of quantum technologies and the need for a structured approach to secure a leading position in this burgeoning field.

SUMMARY: INNOVATION AND INTERVENTION

The year 2023, therefore, was an interesting chapter in the story of quantum technology—one that shows the benefits of a strong, albeit nascent, ecosystem. While capital investment in quantum for 2023 may have fallen short of previous years, research advances and government interest continued and, in fact, increased. This investment slowdown, matched with academic innovation and government intervention, will likely resolve itself in future months and years. In fact, the concerted efforts of academia, industry, investors and governments provide a potent mix to propel the field forward, promising a future where quantum computing is not an esoteric science but a tangible tool that addresses some of the most complex challenges faced by humanity.



THEME 1

Investment landscape: are we in a quantum winter or has it just got a bit colder?

> I wouldn't say a winter, it just got a little colder...
>
> – ALEXEY GALDA, ASSOCIATE SCIENTIFIC DIRECTOR, QUANTUM ALGORITHMS AND APPLICATIONS AT MODERNA

In recent years, the quantum technology sector has witnessed a remarkable surge in venture investments, reaching a zenith in 2022 with over $2 billion invested annually.

This influx of capital marked a significant vote of confidence in an industry at a relatively nascent stage focused primarily on research and development. This sparked debate among observers and analysts concerning if the market was over-inflated. Cautionary whispers of a "quantum winter" started to gain momentum, portraying a scenario of dwindling private investment combined with generative AI diverting attention away from quantum, leading to a slowdown in quantum technological development due to slowing private investment.

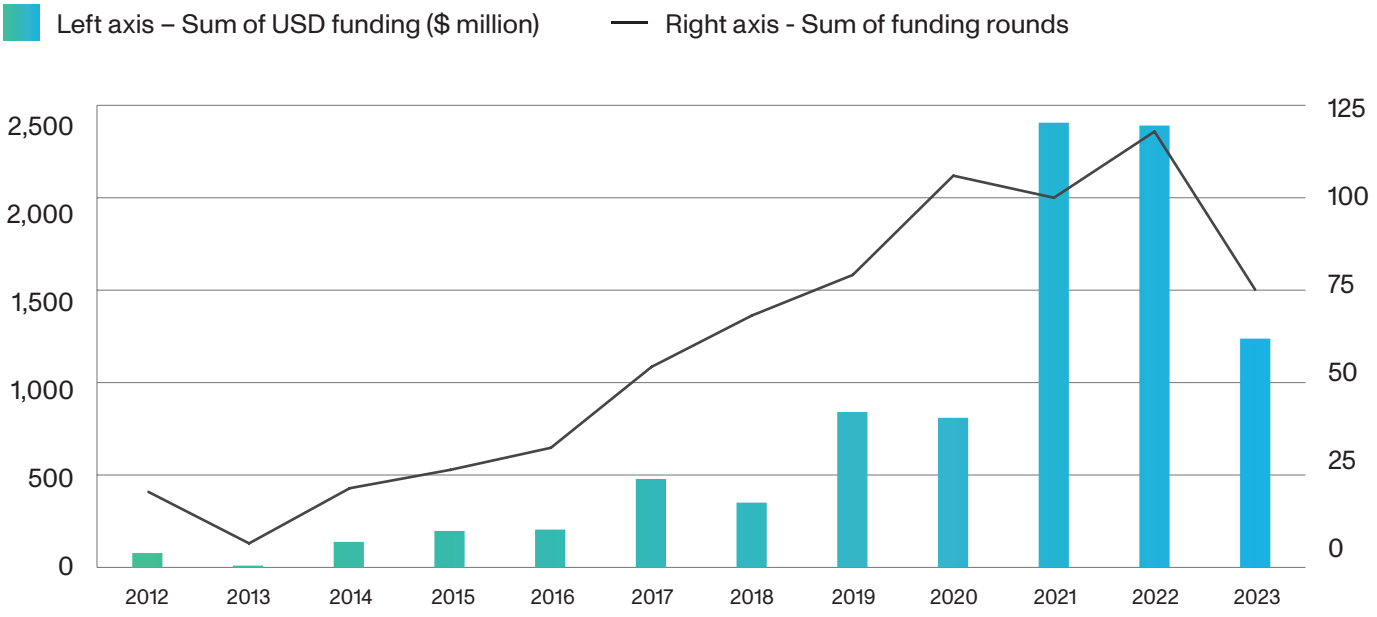
This section aims to shed light on the dynamics of venture investment in the quantum technology market throughout 2023 and detach, somewhat, the link between private investment and quantum advancement. It will explore the underlying factors contributing to the observed investment slowdown, examine the notion of a potential "quantum winter," and provide insights into the key trends shaping the quantum private-public investment landscape in this transitioning year.

Funding Trends In 2023

Private investments in quantum technology peaked in 2022, topping $2 billion.[18] In 2023, the landscape of venture investment in quantum technology presents a contrasting picture.

The year saw a notable deceleration in funding (~50% decline), with disclosed fundraising– and number of investment rounds–significantly lower than the previous two years.

TOTAL PRIVATE INVESTMENT IN QUANTUM TECHNOLOGY ($ MILLION, ROUNDS)



Source: The Quantum Insider, Updated end of December 2023

[18] *The Quantum Insider, The Quantum Intelligence Platform*

However, in this decline, there are critical nuances.

2021 and 2022 were special years. For example, in 2021, we had the large IonQ SPAC and the PsiQuantum Series D round–together representing $1 billion alone.

> There is a huge amount of capital that needs to be raised– that's why we had the SPACs: to overcome the 'Valley of Death'. There are going to be more hardware companies approaching Series C with no money and this is where we will see a problem. Governments are going to try and help with a program to help companies through this.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

It is also important to consider the details when analysing the investment figures.

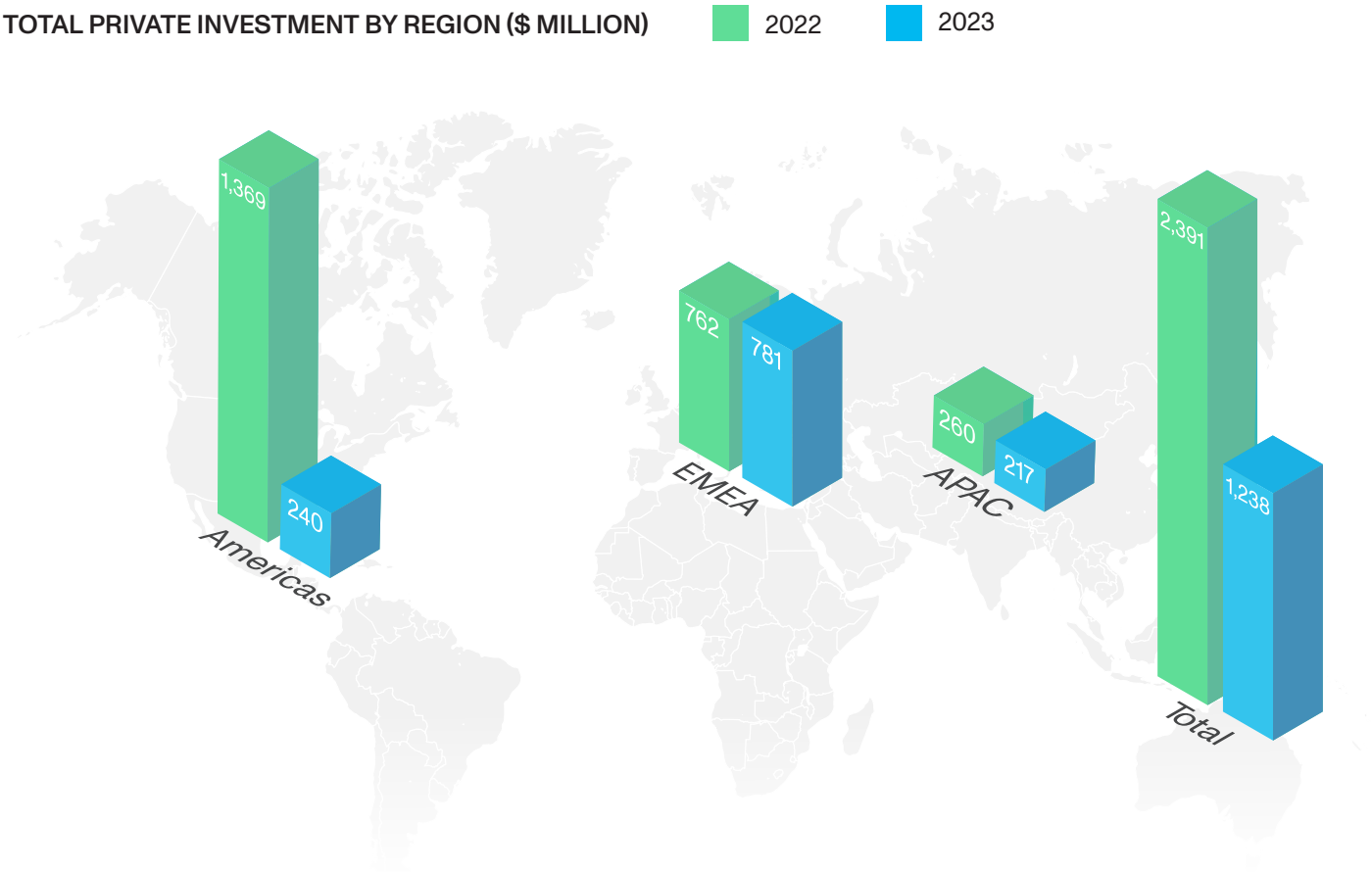
1. Geographical differences
2. VC funding is down overall
3. Growth in government funding

1. Geographical differences

In 2023, the United States saw the biggest fall in venture funding (~80% decline). Yet, this decrease was primarily explained by 2022 being a significant year for quantum technology investments with large rounds fueled largely by SPACs and some select large Series B and later financing rounds.

Comparatively, the APAC and EMEA regions have been relatively more resilient with declines of ~17% in the former and ~3% growth in the latter in 2023 versus last year

TOTAL PRIVATE INVESTMENT BY REGION ($ MILLION)



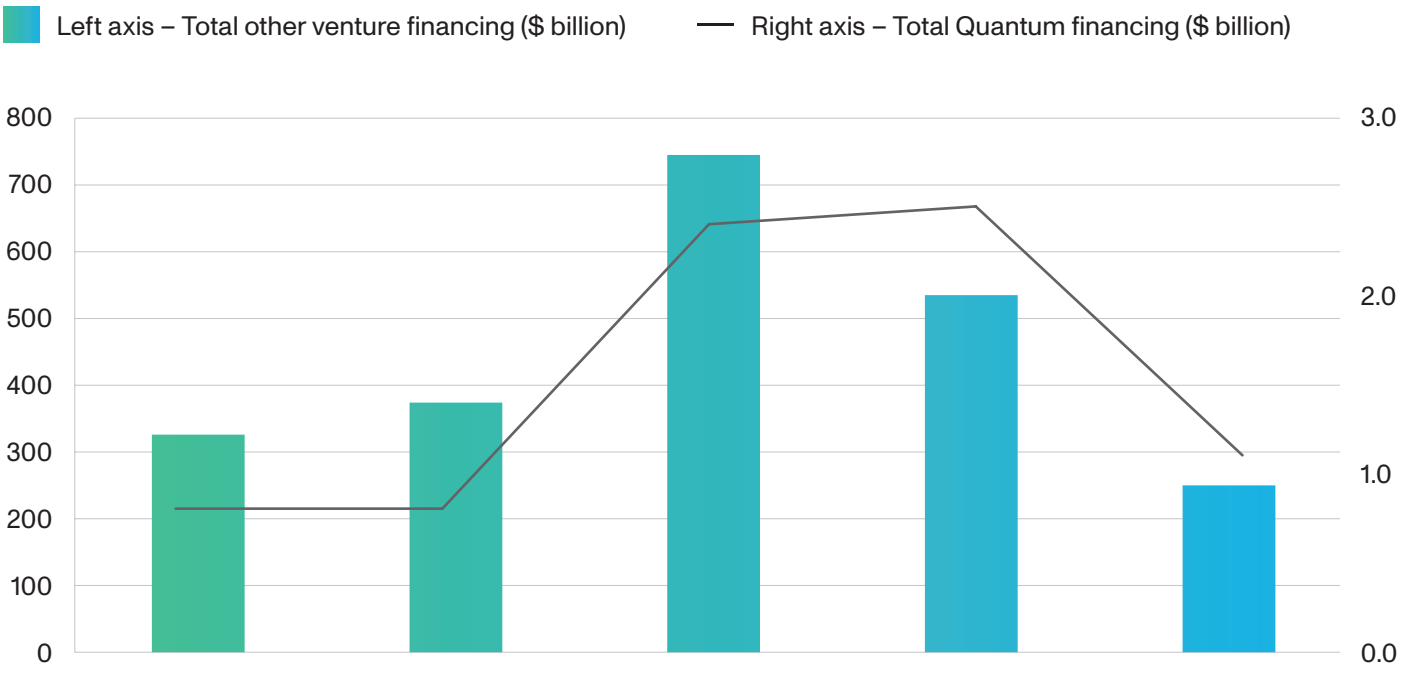
Source: The Quantum Insider, Updated end of December 2023

2. VC funding is down overall

The 10 years leading up to 2021 saw enormous growth in venture capital investment. The USA alone saw >$250 billion of newly deployed capital in 2021, >5x the amount seen in 2011.[12]

The fall of venture investment into quantum technology is in line with the broader venture market as a whole, with both demonstrating ~50% declines in 2023 versus 2022.

TOTAL PRIVATE INVESTMENT IN QUANTUM AND OTHER TECHNOLOGIES ($ MILLION)



Source: The Quantum Insider, KPMG Venture Pulse. Updated only to Q3 2023 YTD for like-for-like comparison purposes.

[19] *OECD Statistics: Venture Capital Investments, USA*

Some media have referenced a 'quantum winter,' however perspectives from the 'boots on the ground' are very different. All interviewees rejected the blanket assertion of a quantum winter:

> Quantum computing enters 2024 stronger than ever. We may have seen the players and investors shift around, but this is nothing like a quantum winter. And a quantum winter is nothing to fear when you remember the quantum ice age a decade ago when very few investors would go near quantum technology. Now we are in an era where investors recognise the opportunities available with quantum and are rushing to back the tech, anxious about missing the arrival of a quantum spring.
>
> – GEORGE GESEK, CHIEF TECHNOLOGY OFFICER AND CO–FOUNDER OF QMWARE

> I don't think we are in a quantum winter, but it is a great catchphrase. Investment is down across the board, so you could say we are in more of a deep tech winter.
>
> – TAHMID QUDDUS ISLAM, QUANTUM TECHNOLOGIES LEAD AT CITI GLOBAL INSIGHTS

> I don't think we are in a quantum winter... In a sense, I see 2021 and 2022 as a sugar rush period... it is challenging for most companies to invest in quantum computing because its practical value is between five to fifteen years away...
>
> – QUANTUM RESEARCH MANAGER AT GLOBAL MULTI–INDUSTRY CONGLOMERATE

> Private investment will probably stay roughly flat with 2023 levels, but this is not as dramatic as a winter might suggest.
>
> – FABIO SANCHES, QUANTUM COMPUTING DIRECTOR AT THE FEDERAL RESERVE

> I wouldn't say we're in a 'quantum winter' – research is continuing, progress is being made – it's just happening at a slower pace. Think of it more as a 'quantum fall'.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

> "I think as long as the industry continues to focus on the delivery of roadmaps and continues to develop the technology, we will likely be able to avoid a 'quantum winter.'
>
> – KEN DURAZZO, VP, DELL RESEARCH

Still, even if the data shows only a relative decline in quantum investment, this does not mean it will be an easy ride for companies in the coming years:

> I wouldn't say a winter, it just got a little colder... When the opportunity space is diluted with more investment options across AI to classical... flow of capital will decrease specifically for quantum.
>
> – ALEXEY GALDA, ASSOCIATE SCIENTIFIC DIRECTOR, QUANTUM ALGORITHMS AND APPLICATIONS AT MODERNA

> Given the current state of technology, some startups could have a difficult time in the next couple of years... we were clear from the beginning that quantum computing is in the stage of basic research... and requires at least ten years to get to an industrial advantage... we need less hype and more realistic expectations.
>
> – MICHAEL STREIF, QUANTUM COMPUTING SCIENTIST AT BOEHRINGER INGELHEIM

Finally, it is important to note that, despite significant growth in quantum investment over the past few years, quantum technology still represents only a fraction of total VC funding (<1%).[20]

[20] *The Quantum Insider, The Quantum Intelligence Platform*

3. Government funding

Focusing purely on the private sector for investment misses a consistent and increasingly important factor in the quantum technology landscape: the public sector. Our interviews flagged quantum computing as a strategically important sovereign technology:

> I have seen over the last three years quantum becoming more important because of competition with China and other countries. I think government support... is significant enough... to drive investment and research in quantum...
>
> – FABIO SANCHES, QUANTUM COMPUTING DIRECTOR AT THE FEDERAL RESERVE

> Investor sentiment towards riskier investments has cooled with the sudden rise in interest rates. Consequently, the continued investment from governments is more important than ever...
>
> – TAHMID QUDDUS ISLAM, QUANTUM TECHNOLOGIES LEAD AT CITI GLOBAL INSIGHTS

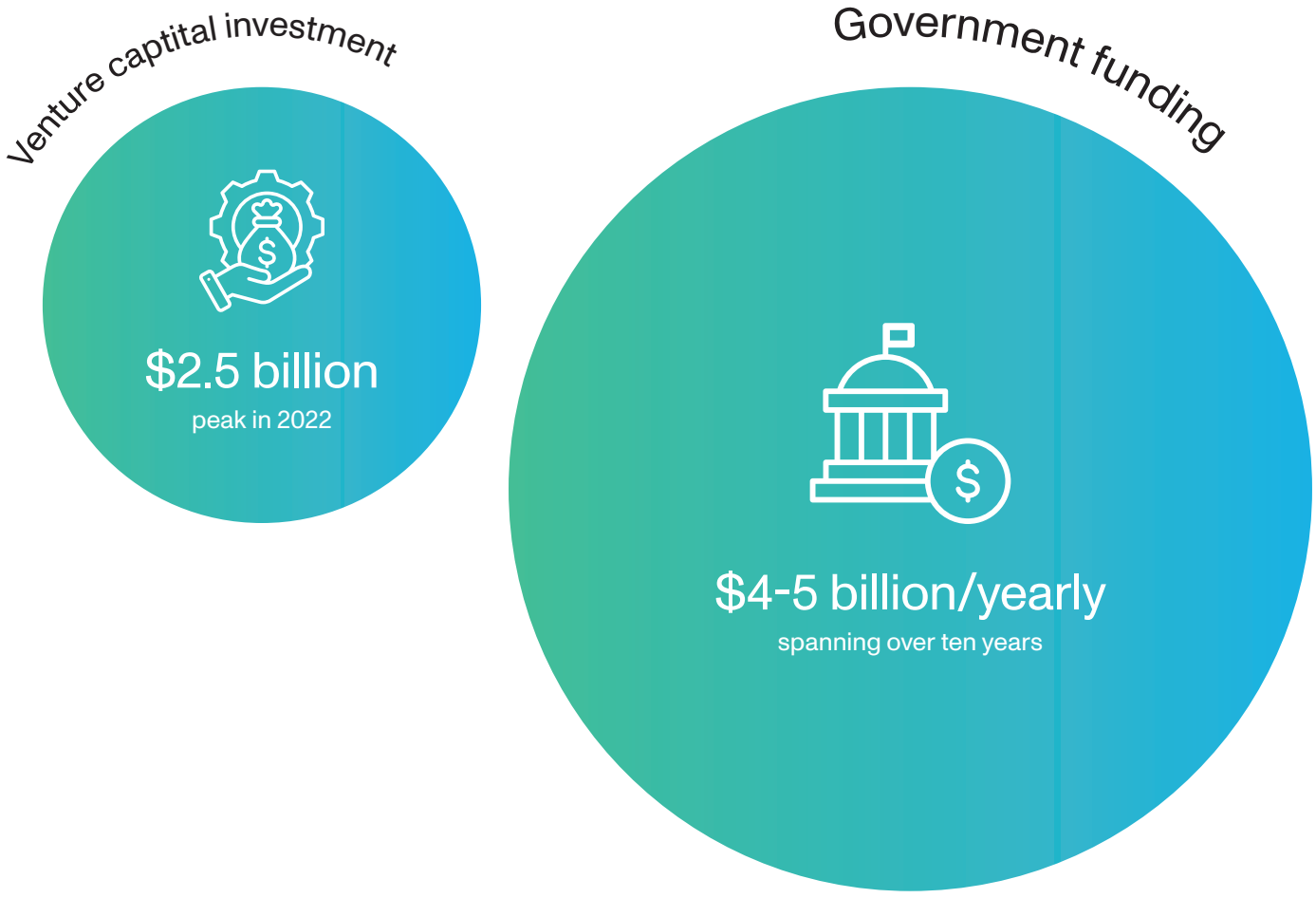
Globally, national governments have committed $40-50 billion in funding. This represents a combination of historical spending and forward-looking commitments. While some of the commitments are subject to political approvals, the message is clear: public commitments currently dwarf private funding.

One notable example is the alignment of the US's CHIPS and Science Act both strengthening the nation's technology companies in response to geopolitical pressures, as well as signifying the nation's public quantum investment commitment, an action that would energize the American ecosystem, as well as resound globally.[21]

It further signals that quantum technology development is not an outlier in technological history for the key role governments have in their maturation. Like the internet and nuclear technology, quantum technologies cannot advance without government support and 2023 showed this public motivation.

[21] *The Quantum Insider: Quantum Leaders: CHIPS And Science Act Could Seed A National Quantum-Centric Supercomputer Program*

If conservatively spread over ten years ($4-5 billion yearly), government funding commitments to quantum represent 2x the quantum VC investment peak in 2022.

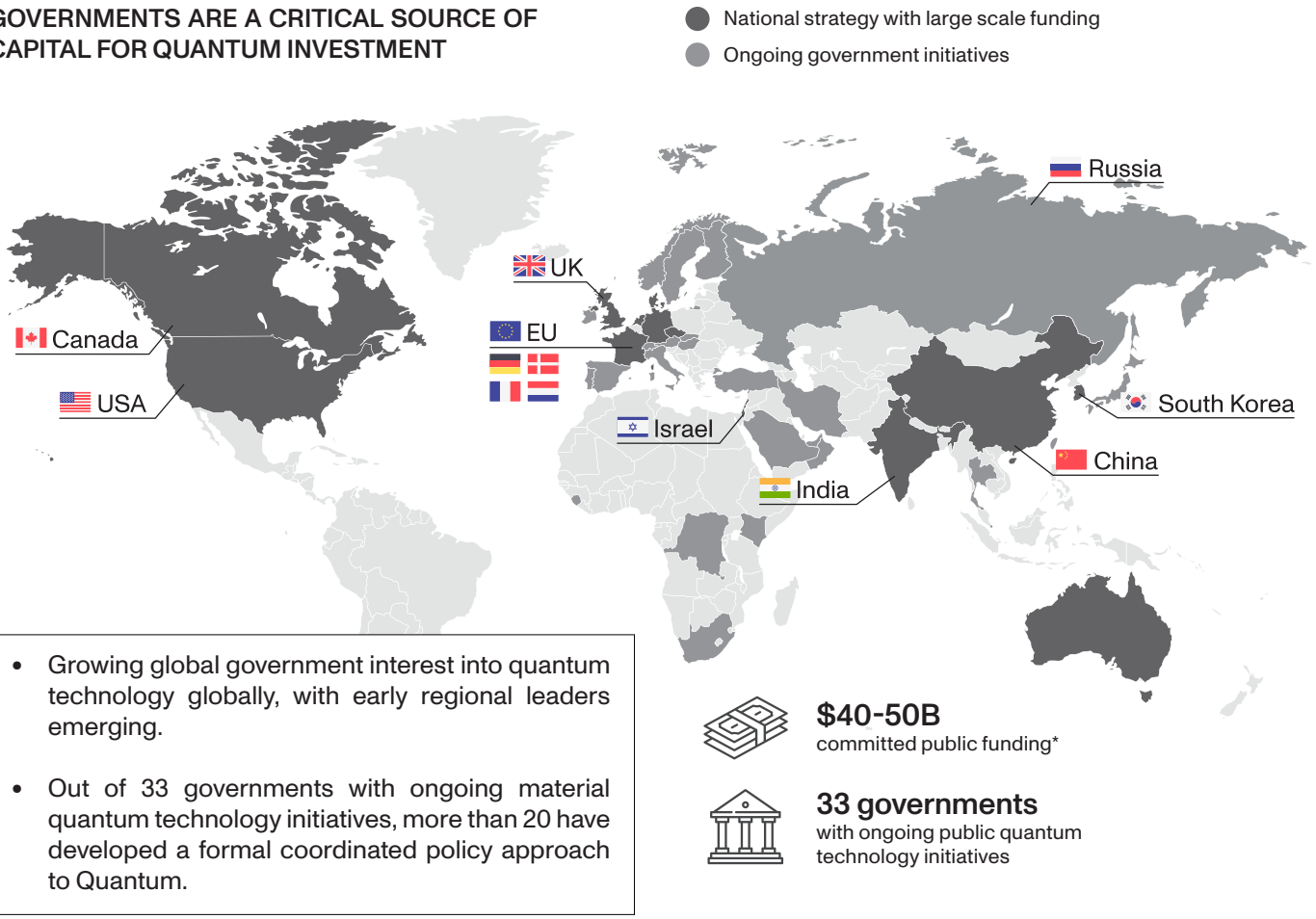


Source: The Quantum Insider analysis

More than 30 governments are actively involved in quantum technologies with expanding international collaborations. Over 20 of these have formulated a formal coordinated policy approach to the promising technology.

During 2023, several governments committed to supporting quantum technologies, realizing the practical applications underpinning them, from secure communication, sensing and navigation to optimization of logistics and infrastructure.

GOVERNMENTS ARE A CRITICAL SOURCE OF CAPITAL FOR QUANTUM INVESTMENT



- Growing global government interest into quantum technology globally, with early regional leaders emerging.
- Out of 33 governments with ongoing material quantum technology initiatives, more than 20 have developed a formal coordinated policy approach to Quantum.

Sources: The Quantum Insider Intelligence Platform

INDIA

INDIA QUANTUM OVERVIEW

TOTAL COMMITMENT
$1.5 billion

EXAMPLE QUANTUM PLAYERS
BosonQ Psi, QNu Labs

PRIMARY AGENCIES
Center for Development of Advanced Computing (C-DAC), Department of Science and Technology, Quantum Research and Center of Excellence

Implemented by the Indian Department of Science & Technology (DST), a quantum mission was initiated in 2020 aiming to advance the nation's economy through quantum technologies and its applications.

In April of 2023, an update to the Indian 2020 plan allocated further government funding commitment which is active until 2025 and totals $1.5 billion to be allocated to seed, nurture and scale up scientific and industrial R&D in quantum while creating an innovative ecosystem in quantum technology.[22]

[22] *Department of Science & Technology, India: Budget 2020 announces Rs 8000 cr National Mission on Quantum Technologies & Applications* and *Cabinet approves National Quantum Mission to scale-up scientific & industrial R&D for quantum technologies*

SOUTH KOREA

SOUTH KOREA QUANTUM OVERVIEW

TOTAL COMMITMENT
$2.4 billion

EXAMPLE QUANTUM PLAYERS
LG Innotek, NORMA, KQC, Samsung

PRIMARY AGENCIES
Korea Institute of Science and Technology, Ministry of Science and ICT, National Research Foundation of Korea, Korea Research Institute of Standards and Science (KRISS)

South Korea's quantum strategy formally started in 2019 with a national initiative titled "Quantum Computing Technology Development Strategy." But the nation's core focus began as recently as this year with a total commitment of $2.4 billion until 2035.

The plan aims to competitively position South Korea in the global quantum technologies industry by advancing core quantum areas and a research ecosystem.

Specifically, South Korea seeks to build its own quantum computer, an ecosystem of quantum sensors, and an increase in its quantum research capacity to 2,500 researchers.

While South Korea's quantum journey is early, ties to the US have already been established with IonQ and IBM Quantum. For example, Sungkyunkwan University's Quantum Information Research Support Center, or "Q-Center," entered a 3-year partnership with IonQ for research and quantum advancement. While further signing an agreement with the Korea Institute of Science and Technology to mature a regional quantum computing ecosystem.

> At heart, I am an optimist about quantum. There is so much change and innovation happening, with teams around the world pushing forward quantum hardware R&D. South Korea is a special place for quantum development. It is leading the way as a global hub, showing the world the value of a complete quantum ecosystem, bringing together government support, a thriving start-up community, and the backing of world-leading universities.
>
> – BRAD KIM, CHIEF QUANTUM OFFICER & SENIOR EXECUTIVE VP

THE UNITED KINGDOM

THE UK QUANTUM OVERVIEW

TOTAL COMMITMENT
$4.3 billion
(new commitment of ~$3.1 billion in 2023)

PRIMARY AGENCIES
Department of Science, Innovation and Technology (DSIT), National Quantum Computing Centre (UKRI), National Physical Laboratory

EXAMPLE QUANTUM PLAYERS
ARQIT, Oxford Quantum Circuits, Quantum Motion, Oxford Ionics, Quantinuum (HQ migrated to Colorado), Riverlane

The UK National Quantum Strategy pledged to commit £2.5 billion ($3.1 billion) in 2022 with one of the most ambitious national plans seen in the quantum industry.

The UK quantum road map spans the next ten years and focuses on maintaining the UK's strong position in quantum investment, technology, and corporate presence. The initiative further aims to establish a network of quantum research hubs and an accelerator program to align research, industry and government on quantum while pushing for commercial viability.

Namely, the national quantum strategy pushes for ecosystem clusters across the UK, such as advanced semiconductors in South Wales and photonics in Scotland.

Finally, the UK is also active in forming numerous alliances with other nations and clusters, such as the EU, the USA, Canada, Japan, South Korea, Australia, and more.

The latest came from an Autumn Update outlining five quantum missions acting as milestones for quantum technology until 2035, covering aims such as gaining quantum advantage and establishing a quantum communication network.[23]

[23] *UK Government – Department for Science, Innovation & Technology: Policy paper*

THE UNITED STATES OF AMERICA

USA QUANTUM OVERVIEW

TOTAL COMMITMENT
At least $4.0 billion

PRIMARY AGENCIES
National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the Department of Energy (DOE)

EXAMPLE QUANTUM PLAYERS
Google Quantum AI, IBM Quantum, Microsoft, IONQ, SandboxAQ, PsiQuantum, Rigetti, and Infleqtion

Not accounting for material defense investments and other initiatives such as ones from DARPA, the US government has pledged total quantum funding of at least $4.0 billion, through the National Quantum Initiative (NQI) and other funding initiatives.

The NQI was passed by the House Committee on Science, Space, and Technology in December 2023, and focuses quantum technology around three findings published in a report while announcing 2024 to be a critical year for quantum in the US with a proposed budget to strengthen quantum research and advancement.[24]

It further aims to accelerate quantum research and practical development for its economy and security through select agencies such as the National Institute of Standards and Technology (NIST) and the Cybersecurity & Infrastructure Security Agency (CISA).

What signifies the US public quantum investment commitment is the alignment with the CHIPS and Science Act aimed at strengthening domestic technology companies in response to geopolitical pressures.

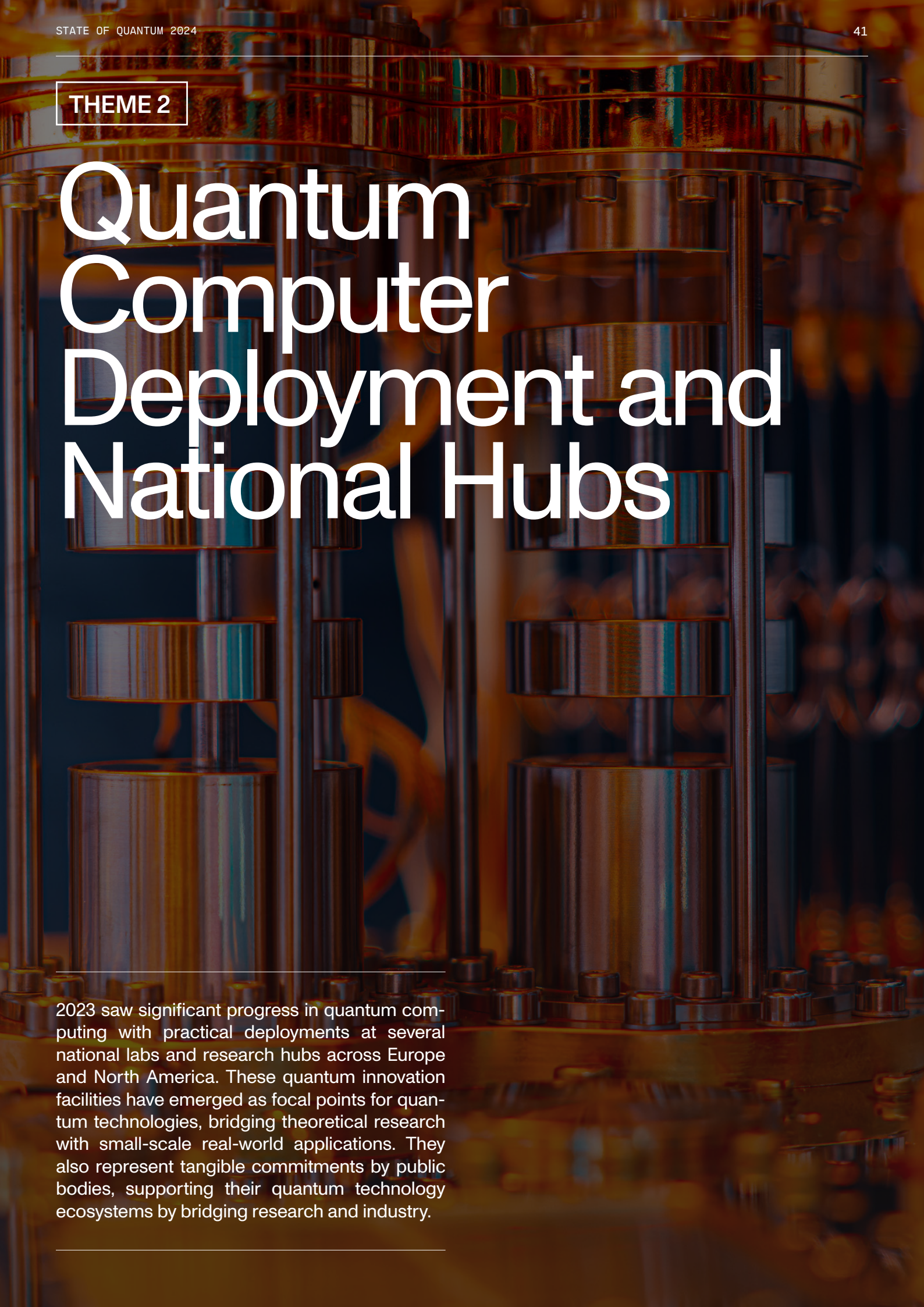
Workforce advancement has been initiated to target mounting shortages in quantum skills, named the National Strategic Plan for Quantum Information Science and Technology Workforce Development.

In addition to the nation's healthy private investment ecosystem, the United States' significant governmental backing of quantum technologies and initiatives further fuels its notable private quantum players and research legacy.

[24] *The Quantum Insider: US Releases National Quantum Initiative Budget Supplement, Committee Passes NQI Reauthorization Act*

THEME 2

Quantum Computer Deployment and National Hubs



2023 saw significant progress in quantum computing with practical deployments at several national labs and research hubs across Europe and North America. These quantum innovation facilities have emerged as focal points for quantum technologies, bridging theoretical research with small-scale real-world applications. They also represent tangible commitments by public bodies, supporting their quantum technology ecosystems by bridging research and industry.

Practical Quantum Computing in National Hubs

In this section we profile seven national centers, offering quantum computational resources for research and commercial purposes in a wide range of quantum computing types, industrial focuses, and locations across Europe, North America, and beyond.

HOUSE OF QUANTUM

Situated in Delft, the Netherlands - a small city positioning itself as a central location for quantum technology- House of Quantum is a Dutch quantum hub with paired locations in Eindhoven, Twente, and Amsterdam, many of which open in 2026.

House of Quantum connects experts, researchers, and industry players to advance quantum computing from theory to practice, providing availability to cryolabs, cleanrooms, and offices.

Notable members and partners include Fujitsu, Qutech, TNO, TUDelft, OrangeQS, Qblox, Qphox, QuantWare, Delft Circuits, Single Quantum, Q Bird, Bluefors, Microsoft, Quantum Delft, and Quantum Delta NL.

One example of a cryolab at the Dutch House of Quantum is the Bluefors Lab.

The Bluefors Lab is lowering the barrier of entry into cryogenic quantum computing by offering a millikelvin measurement system to test Noisy Intermediate-Scale Quantum (NISQ) computing systems. Such a testing ground enables startups, researchers, or other entities to assess the function, viability, reliability, and scalability of its quantum computing solutions. The cryolab further provides the means to test post-error-corrective mechanisms such as algorithms and middleware with the quantum hardware. As an example of how Bluefors is facilitating real-world quantum computing systems, IQM is using Bluefors dilution refrigerators in both the IQM Spark and IQM Radiance models, which the company unveiled this year.

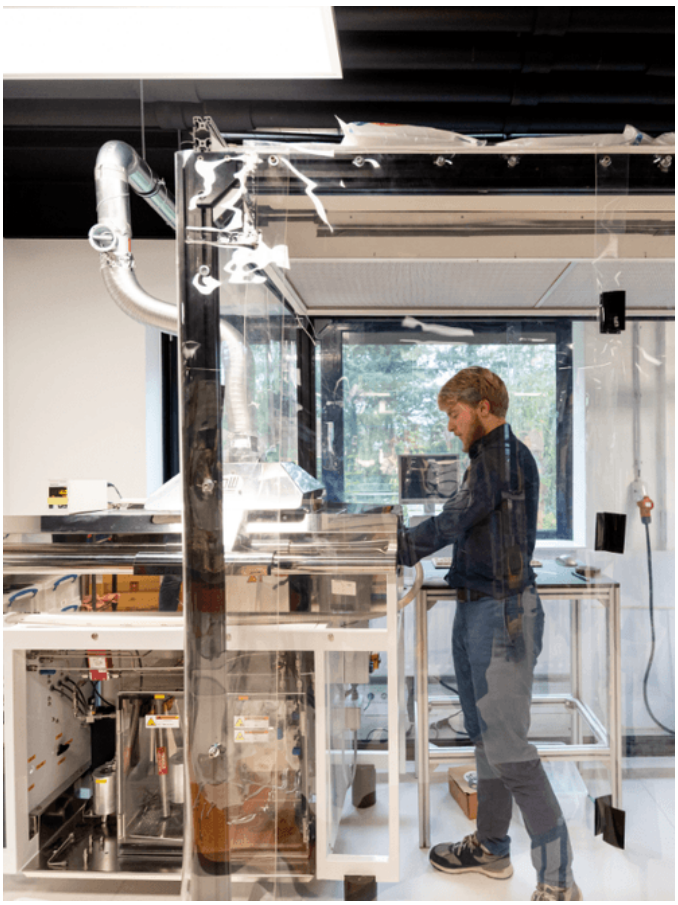


Image: House of Quantum

SHERBROOKE QUANTUM INNOVATION ZONE

Located in Québec, Canada, the Sherbrooke Quantum Innovation Zone is a municipality-managed national lab in quantum technologies with more than $435 million of funding commitments.[25]

The aim for Sherbrooke is distinctly local in utilizing quantum technology to improve immediate manufacturing and technology businesses in the region while attracting renewed capital and highly skilled jobs.

The expanding list of partners includes 1Qbit, Exaion, Nanoacademic, Nord Quantique, Pasqal, Qubic, SBQuantum, CMC Microsystems, PinQ2 City of Sherbrooke, Université de Sherbrooke, Sherbrooke Innopole, Cégep de Sherbrooke, Productique Québec, and Center 24-juin.

The innovation zone covers three locations:

- Institut Quantique, connects researchers in quantum materials, engineering, and information to develop the future of quantum technologies.
- CINQ is focused on talent building and preparing businesses and universities for digital technologies and advanced manufacturing, quantum included.
- Espace Quantique 1 is a collaborative space with shared lab facilities to advance the practical use cases of quantum technologies. Pasqal, one of the partners, has announced they will be deploying a neutral atoms quantum computer for testing purposes in the shared lab with the means to produce quantum processing devices.

Image: Martin Blache, collaborator UdeS

[25] *Innovation News Network: Accelerating Innovation in Quantum Technologies*

ISRAEL QUANTUM COMPUTING CENTER

The Israel Quantum Computing Center, with $29 million in private and public funding[26], will deploy a full-stack quantum computer providing researchers and industry players to test the qubit types: superconducting qubits, cold ions, and optical computers.

The Israel Innovation Authority (IIA) chose Quantum Machines to deploy the full-stack quantum computer backed by international partners of Elbit Systems, Quant-Ware, ORCA, Infleqtion, ParTec, and Classiq.

The Israel Quantum Computing Center will offer a diverse set of quantum computing modalities for research and testing. A strategy that aims to explore and identify the most suited quantum computing types for different use cases and eventually quantum advantage.

Image: Quantum Machines

[26] *The Quantum Insider: Israel To Establish $29M Quantum R&D Centre*

QUANTUM BASEL, THE CENTER OF COMPETENCE FOR QUANTUM AND ARTIFICIAL INTELLIGENCE

2023 also saw IonQ's deployment of its new 20 "algorithmic qubits" quantum computer, named 'Aria.' The quantum computer is located in Quantum Basel, the Center of Competence for Quantum and Artificial Intelligence, in Switzerland. The new quantum center is part of the uptownBasel innovation campus, a 70,000 square meter complex offering companies and research institutions ways to advance Industry 4.0 technologies, specifically in the pharmaceutical sector.

Through Quantum Basel's partnership with IBM Quantum, cloud access is offered to IBM Quantum's System One and System Two quantum computers.

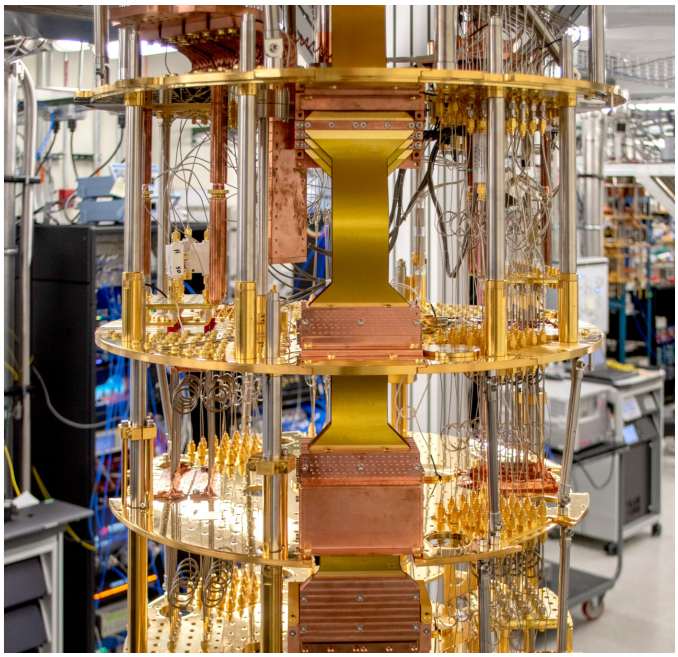


Image: QuantumBasel

NATIONAL QUANTUM COMPUTING CENTER UK

Cross-sectoral collaboration is the central aim for the UK's National Quantum Computing Center (NQCC) opening the doors to its physical center in Harwell in 2024. The hub aims to develop synergistic effects between academia, research institutions, and businesses to progress quantum computing for the UK industry and economy.

One of the ways NQCC executes this goal is by providing optical and cryogenic quantum computing platforms for testing and research on hardware and post-corrective software.

This is to realize NQCC's objectives of developing a quantum-ready workforce in the UK and pushing the practical applications of quantum computing to the British economy and infrastructure aligned with its national quantum strategy and missions.

The upcoming UK quantum hub is establishing an international network of partners such as IBM Quantum and Rigetti Computing to further combine with its quantum research activities.

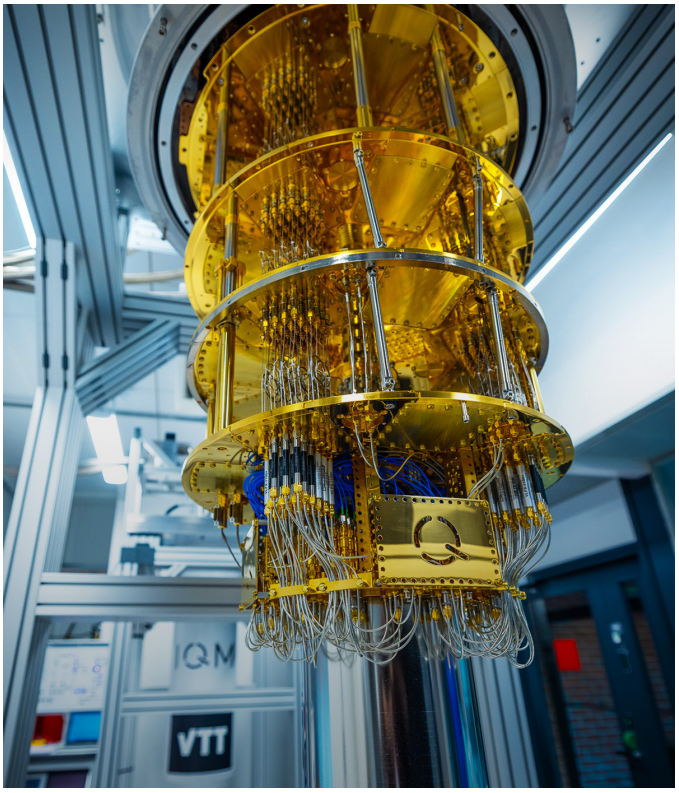
VTT TECHNICAL RESEARCH CENTER OF FINLAND

With IQM Quantum Computers (IQM) as the partner, VTT Technical Research Center of Finland upgraded its quantum computing capabilities to 20 qubits this year from its 5-qubit quantum computer deployed in 2021.

This milestone is part of Finland's national strategy for quantum computing, committing $74 million to achieve a 54-qubit quantum computer by the end of 2024 with IQM and a goal of 300 qubits later.[27]

This plan is part of IQM Radiance, a high-performance computing platform for data centers, enabling users access to quantum system operations in existing environments, experimenting with algorithm behavior, and general quantum computing applications.[28]

The newly deployed 20-qubit quantum computer is located in the southern end of Finland and provides researchers in micro and nanotechnology with quantum computation.



Images: VTT

[27] *HPC Wire: IQM and VTT Unveil Finland's 2nd Quantum Computer with 20 Qubits*
[28] *The Quantum Insider: IQM Quantum Computers Aims at 150-Qubit System With 'IQM Radiance'*

THE POLISH POZNAŃ SUPERCOMPUTING AND NETWORKING CENTER (PSNC)

As the technology and science scene in Poland advances, the Polish Poznań Supercomputing and Networking Center (PSNC) has chosen the British optical quantum computing vendor, ORCA Computing, to deploy two of its PT-1 quantum photonics systems.[29]

The two quantum computers are to be installed in December 2023 and will support research into the fields of biology and chemistry aided by machine learning, while positioning Poland as one of the early national players in biotechnology, generative chemistry, and quantum simulation.

The deployment of the two optical quantum computers will also encourage closer collaboration between quantum technologies, hybrid systems, and classical high-performance computing. Namely this initiative is to explore intersections between machine learning and quantum computing: between GPUs and Quantum Processing Units (QPUs).

[29] *The Quantum Insider: ORCA Computing to Provide Poznań Supercomputing And Networking Center With First Quantum Computers*

Quantum Computing Deployment and Collaboration

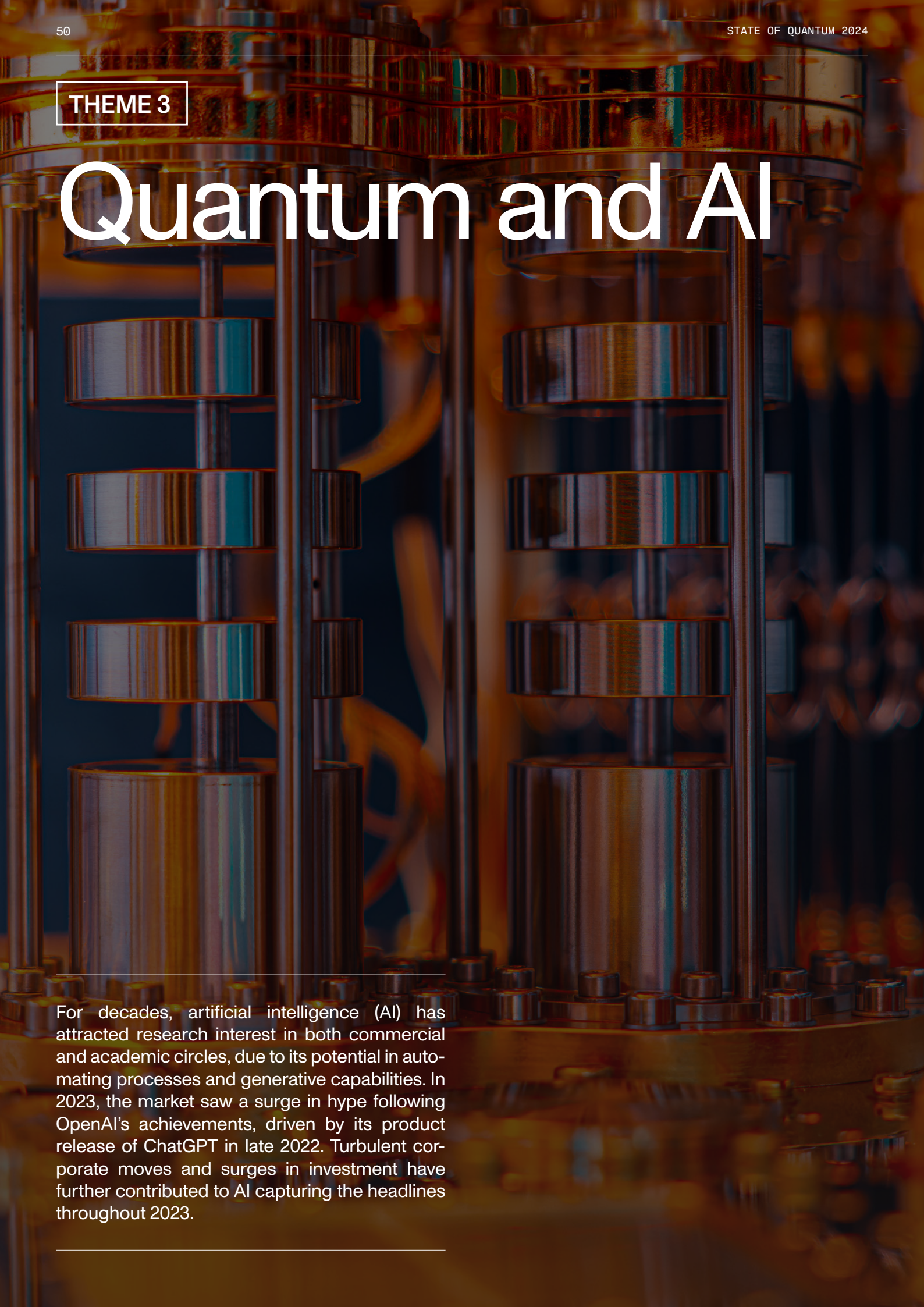
In summary, 2023 saw a concerted effort to deliver tangible quantum computing resources for commercial and research purposes.

A notable development in the quantum computing roadmap is that national governments prioritized strategic investments to lay the groundwork for the deployment of actually working quantum computers.

Notably, the deployments of the quantum systems are of varying types, while dedicated to advancing collaboration and innovation between multiple stakeholders, supporting quantum technologies to progress from labs to markets and theory to applications.

THEME 3

Quantum and AI



For decades, artificial intelligence (AI) has attracted research interest in both commercial and academic circles, due to its potential in automating processes and generative capabilities. In 2023, the market saw a surge in hype following OpenAI's achievements, driven by its product release of ChatGPT in late 2022. Turbulent corporate moves and surges in investment have further contributed to AI capturing the headlines throughout 2023.

AI IS CAPTURING THE LIMELIGHT

This year, Large Language Models enabled by a transformer-based neural network computing architecture and powered by GPUs became the driving infrastructure behind the ongoing AI revolution we are experiencing today.

Mirroring other transformative technologies, the prominence of AI has occupied executive and investor consciousness to a point where some end-users of quantum technologies are shifting gears to focus on AI first: quantum second.

> Generative AI is gaining a lot of traction and resources are going there... you have to figure out how to stay relevant and convince the board that investment in innovation must span time horizons beyond near-term.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

> I would say I've seen quite a few people starting to question when quantum is able to show a computational advantage in a single big and relevant use case. And right now AI is top of mind as one of those potential use-cases.
>
> – KEN DURAZZO, VP, DELL RESEARCH

> Generative AI seems to be where most investment is going, casting a shadow on quantum. It's a lot easier to convince boards to invest into generative AI compared to quantum, which is considered as more frontier.
>
> – TAHMID QUDDUS ISLAM, QUANTUM TECHNOLOGIES LEAD AT CITI GLOBAL INSIGHTS

This surge in AI popularity has prompted the question if generative AI has pivoted attention away from quantum technologies and if quantum is left in the dust.

AI VERSUS QUANTUM

> A lot of the VC community has over-pivoted to generative AI and could be a reason why we are seeing investment go down in quantum systems compared to the last couple of years.
>
> – KEN DURAZZO, VP, DELL RESEARCH

Quantum computing should not be seen as an alternative to generative AI and machine learning. They are complementary.

While VC investment in quantum technologies has decreased, a spillover effect has emerged between artificial intelligence and quantum.

> While I see this as part of a broader technology downturn, we do see AI investment going up, including in hardware. This ends up helping quantum because both quantum computing and specialized AI hardware are "new chips" and transformative technologies.
>
> – FABIO SANCHES, QUANTUM COMPUTING DIRECTOR AT THE FEDERAL RESERVE

The sudden surge in interest in generative AI has underlined the importance - and challenges - of being ready for transformational technologies. AI is capturing the limelight but it flags that corporations must be prepared for the next transformative technology.

> The sudden improvement in the capabilities of generative AI caught a lot of companies off-guard. That'll be a lesson they'll take forward when investigating other disruptive technologies, like quantum. The transition from AI promise to execution is taking place, which could give quantum some breathing room.
>
> – TAHMID QUDDUS ISLAM, QUANTUM TECHNOLOGIES LEAD AT CITI GLOBAL INSIGHTS

It's important to carefully delineate how quantum and AI are relevant to each other.

Quantum computing as a potential HPC and AI accelerator: A key adoption barrier to on-premise AI, and by extension cloud-accessed AI, is GPU availability from the infrastructure of GPU centers, sufficient scaling of advanced semiconductor manufacturing, and global supply chain challenges from geopolitical complications.

Some expect quantum computing could help provide the processing power required for AI or its development. However, as AI is designed on linear classical computing, traditional machine learning algorithms can't run on quantum processing units (QPUs). Yet, as quantum machine learning (QML) analogues advance, quantum computing can assist the development of generative AI and automation. While still in its infancy, quantum computing could improve the training of neural network models or expedite certain linear algebra operations and, by extension, optimize machine learning tasks.

> Some people are starting to catch on to the performance improvement potential in Machine Learning using Quantum Machine Learning models. Quantum computers aren't just faster, but they could learn better. My focus is currently on trying to scale those, either on a quantum computer or in a quantum-inspired way, to deliver real and meaningful value.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

AI supporting the development of quantum computing: Usage of today's AI could aid the adoption and development of quantum computing to address complex technical barriers such as decoherence and relaxation of qubits while improving the effectiveness of post-error-correcting algorithms.

In effect, possibly expediting the development of quantum computing to potentially be fault-tolerant, reliable, and scalable for its widespread commercial application.

2023 saw potential use cases from the alliance between quantum technologies and AI. These use cases, such as generative chemistry and the simulation of digital twins, are very much in their early infancy. However, the parallel maturation of quantum computing and AI could potentially bring improvements that promise to solve computationally challenging problems.

> Some... are asking 'what can I do today with AI on quantum?' AI is going to get a lot of focus over the next few years and... understanding the role of quantum as a potential accelerator... it's reasonable to ask if quantum computers aren't more suited for probabilistic computing systems. We may have to change some of the ways that we approach algorithms and perform tasks in AI to fully utilize the full potential of quantum computers.
>
> – KEN DURAZZO, VP, DELL RESEARCH

> I am excited to see what we can achieve from combining generative AI with quantum before we get to fault-tolerant quantum computation... Quantum Machine Learning may give us some advantage over other heuristic classical algorithms.
>
> – ALEXEY GALDA, ASSOCIATE SCIENTIFIC DIRECTOR, QUANTUM ALGORITHMS AND APPLICATIONS AT MODERNA

The potential impact of the convergence between quantum computing and artificial intelligence is still nascent. However, the next stage of AI is being able to execute sequenced tasks over planned periods.

This means rather than immediate questions and answers from generative AI, it will be able to act on a set of tasks, changing its execution based on ongoing results.

With the AI and quantum computing excitement and their potential use cases, we should expect spillover in supporting the development of the two emerging technologies.

> In finance, the recent uptake in the use of generative AI has added another dimension to the potential of using quantum computing for machine learning. For many use cases, while it looks promising, we're still at the early research stages...
>
> – TAHMID QUDDUS ISLAM, QUANTUM TECHNOLOGIES LEAD AT CITI GLOBAL INSIGHTS

Quantum technologies and Artificial Intelligence are not adversaries. The two are complementary, possibly even crucially connected - eventually.

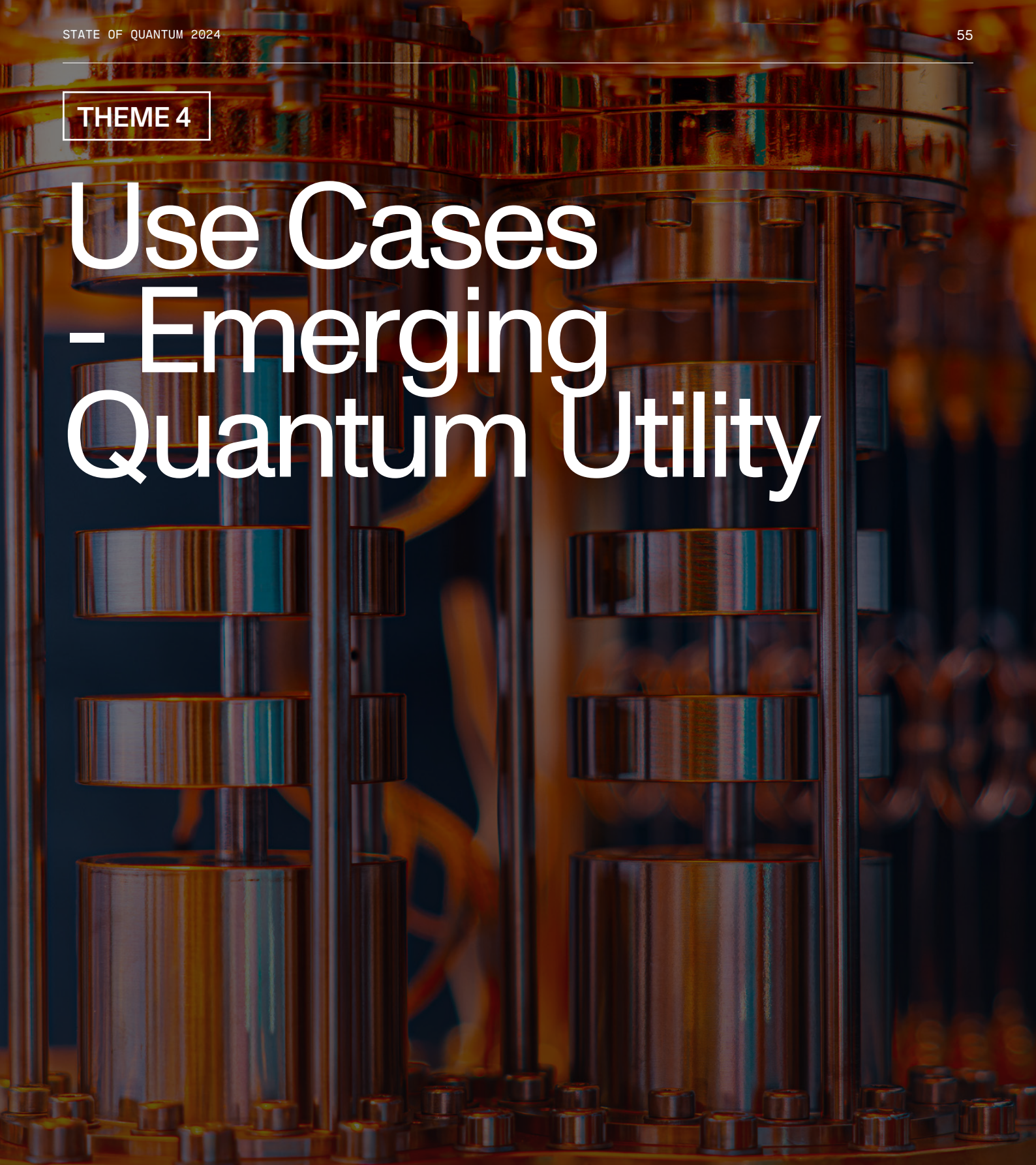
Through pioneering quantum layers and hybrid model architectures, we have been actively shaping the confluence of quantum and artificial intelligence to augment and amplify our capacity to predict, understand, and innovate.

Hybrid Quantum Neural Networks (HQNNs) are a powerful tool to help industry tackle specific types of machine learning problems, such as time series prediction. Our endeavors in renewable power forecasting, steam mass flow predictions and drug response analysis demonstrates the potential of better accuracy with less data. We are harnessing the power of our novel approaches such as Parallel Hybrid Networks, Quantum Depth Infused Layers, and Exponential Encoding. We are also working on a powerful framework that makes Quantum AI accessible, through empowering users to design, build, tune, benchmark and deploy quantum enhanced ML models, in our Quantum-as-a-Service TQ42 Ecosystem.

– KARAN PINTO, GLOBAL DIRECTOR OF GROWTH AT TERRA QUANTUM

THEME 4

Use Cases - Emerging Quantum Utility



In this theme, we categorize quantum computing's developing use cases. Echoing the insights of the 2022 State of Quantum report, the most immediate quantum technologies use cases that indicate initial value are centralized around three areas: healthcare, cybersecurity, and financial services.

This section will thus expand on the growing field of exploring use cases for quantum. Each is interspersed with insights from experts in the industry, alongside the recognition that billion-dollar value is only possible from quantum technologies achieving maturity and advantage over classical and hybrid systems.

Use Cases Recap of the 2022 Report

The State of Quantum 2022 report found that more than 63% of surveyed companies expected commercial applications in the next five years. This left a significant portion who didn't believe quantum computing was yet practical enough for real-world applications. The reasons cited were:

- High prices
- Unreliable hardware
- A necessity for significant capital investment
- Shortage of required talent in quantum technologies

In this section we dig into the potential use cases, focusing on three clear industries–healthcare, cybersecurity, and finance– which stood out in respondents' answers to be impacted most by quantum computing. With additional insights from 2023, how did these three industries perform, and, further, which other quantum computing use cases stand to offer users increased revenue or decreased cost if quantum computing achieves maturity and advantage?

The Quantum Insider tracked a doubling in enterprise end-users, from 150 to 300[30], interested in quantum technologies and their potential from simulation to optimization.

The table below provides key examples of partnerships between an end-user and a quantum technology supplier.

[30] *The Quantum Insider, The Quantum Intelligence Platform*

Quantum Company	Enterprise User	Description
AUTOMOTIVE AND AEROSPACE		
Quantinuum	BMW and Airbus	BMW Group, Airbus, and Quantinuum joined forces to accelerate sustainable mobility research using quantum computers. This collaboration aims to leverage the power of quantum computing to address challenges in the field of sustainable transportation.
RIKEN and Fujitsu	Toyota	RIKEN and Fujitsu's Fugaku supercomputer will partner with an alliance of companies including Toyota, Hitachi, and Sony to promote the use of computing infrastructure that melds quantum technology with supercomputers. Through the integration of the RIKEN-Fugaku supercomputer, Japan's Riken research institute aims to bring quantum computing technology into real-world use by around 2025.
Terra Quantum	Honda	Terra Quantum and Honda Research Institute Europe developed a quantum machine learning solution to expedite routing during disasters. Demonstrated in a simulated earthquake, the solution efficiently predicted vehicle escape routes, outperforming classical methods. It processes many real-time variables, aiming for implementation in various urban scenarios.
Terra Quantum	Schaeffler	Schaeffler Group and Terra Quantum initiated a collaboration, integrating quantum computing and AI to advance mobility and manufacturing. Their partnership focuses on business use cases, sets a clear application roadmap, and provides quantum training, aiming to enhance Schaeffler's innovation and operational performance in areas of general manufacturing.
ENERGY		
Terra Quantum	Uniper	Uniper and Terra Quantum partnered to apply hybrid quantum computing to the energy sector. They targeted enhancements in LNG logistics, CO2 emissions predictions in biomass plants, and valuing complex derivatives in energy trading, demonstrating practical quantum technology use cases in the energy sector.
FINANCE		
Quantinuum	HSBC	Quantinuum and HSBC announced a series of exploratory projects that exploit the potential near- and long-term benefits of quantum computing for banking with specific projects in cybersecurity, fraud detection, and natural language processing.
Terra Quantum	HSBC	Terra Quantum collaborated with HSBC to apply hybrid quantum technologies to optimization challenges in finance. This partnership aims to enhance efficiency and manage complex problems like collateral optimization with Terra Quantum's proprietary TetraOpt solver, demonstrating quantum's growing impact on the financial industry.
Terra Quantum	Cirdan Capital	Terra Quantum and Cirdan Capital partnered to optimize exotic option pricing with quantum software, achieving up to 75% faster calculations than standard methods. This advance allows for efficient risk assessment and potential cost savings in financial trading, indicating readiness for quantum-powered solutions in the future.
HEALTH CARE		
Google Quantum AI lab	Bayer	Bayer aims to speed up its in-silico research and development with Google Cloud's high-speed processors. This collaboration aims to enable Bayer to run large quantum chemistry calculations at scale using Google Tensorflow Processing Units.
IBM	Moderna	Moderna and IBM are teaming up to use generative artificial intelligence and quantum computing to advance mRNA technology, the development at the core of the company's Covid vaccine. The companies have signed an agreement that would allow Moderna to access IBM's quantum computing systems and generative AI model.

Quantum Company	Enterprise User	Description
INDUSTRIALS		
Microsoft	Johnson Matthey	Scientists who specialize in chemistry at Microsoft Azure Quantum partnered with Johnson Matthey to discover novel types of catalysts for hydrogen fuel cells. This collaboration showcases the potential of quantum information science in reducing the carbon footprint of the automotive industry and finding solutions to tackle the issue of climate change.
Xanadu	Rolls-Royce	Xanadu and Rolls-Royce will collaborate to accelerate aerospace research by co-developing new PennyLane features.
Infleqtion	World View	Infleqtion and World View announced a partnership that provides faster, more cost-effective quantum application testing utilizing Infleqtion's compact quantum technology and World View's patented stratospheric balloon systems.
INFORMATION TECHNOLOGY		
Quantum Brilliance	Beyond.pl	The cooperation will focus on the acceleration of market adoption of quantum computing technology and solutions in CEE.
Quantum Computing Inc	millionways	Quantum Computing Inc and millionways are working to investigate the benefits of combining QCI's Reservoir Quantum Computing (RQC) machine learning technology with millionways' AI algorithms. QCI hopes to launch a commercialized application or product utilizing their quantum photonic hardware and AI.
Quantinuum	Microsoft and KPMG	KPMG and Microsoft are working with Quantinuum in Simplifying Quantum Algorithm Development via the Cloud. The QIR Alliance, an international effort to enhance platform interoperability and enhance the work of quantum computing developers.
Quantinuum	Cybertrust	Quantinuum announced that Cybertrust has integrated its Quantum Origin quantum-computing-hardened private keys into a new certificate issuance and distribution platform for IoT devices to ensure secure communications now and into the future.
RIKEN	Sony	RIKEN and Fujitsu's Fugaku supercomputer will partner with an alliance of companies including Toyota, Hitachi, and Sony to promote the use of computing infrastructure that melds quantum technology with supercomputers. Through the integration of the RIKEN-Fugaku supercomputer, Japan's Riken research institute aims to bring quantum computing technology into real-world use by around 2025.
Oxford Quantum Circuits	Equinix	Oxford Quantum Circuits is installing their Quantum Computer in Equinix's Data Centers with plans to open access to businesses globally.
UTILITIES		
PASQAL	POSCO	POSCO Holdings New Experience of Technology Hub plans to conduct research and development of quantum AI algorithms jointly with PASQAL. The two companies plan to focus their capabilities on developing innovative technologies such as optimizing the hydrogen reduction steelmaking process (HyREX) and developing secondary battery materials by combining POSCO Group's AI technology and PASQAL's quantum computer technology.

Four key industries affected or enabled by quantum computing

Four categories denote the potential practical applications of quantum computing, which matured or formed in 2023.

From a broad perspective, quantum computing use cases fit into three areas, with the last category acting as being potentially impacted by quantum computing:

1. SIMULATION

2. OPTIMIZATION

3. MACHINE LEARNING

4. SECURITY

Within these categorizations, several practical applications, spanning verticals and industries, exist from quantum's potential benefits or its impact on existing activities.

Tackling the highlighted industries–healthcare, security, and finance–from last year's report, we see the sentiments of value potential echoed this year.

Throughout this report, we have referenced Boston Consulting Group's value impact potential delineated by vertical and industry, as a high-level estimate of the scope of importance if quantum computing manages to achieve advantage and widespread commercial usage.[31] We would caution that this should act merely as a high-level guide to future opportunities, not a precisely calculated figure.

[31] *Boston Consulting Group: What Happens When 'If' Turns to 'When' in Quantum Computing?*

SIMULATION AND MACHINE LEARNING IN HEALTHCARE

BCG US$ value creation impact estimate: $60-130bn

Two quantum computing applications stand out in potentially improving and shortening drug discovery. A process that, on average, takes over a decade with a minuscule success rate and a cost per drug over $2 billion.[32]

When combining machine learning and quantum computing, better simulation of chemical compounds, micro- and macromolecule interactions and behavior could be possible. A use case in early drug discovery that could improve and expedite the identification of potential new drug modalities.

> ...there are many computational tasks in the drug design pipeline that could benefit from quantum computing... for example the design of mRNA sequences to achieve the desired function of the drug...
>
> – ALEXEY GALDA, ASSOCIATE SCIENTIFIC DIRECTOR, QUANTUM ALGORITHMS AND APPLICATIONS AT MODERNA

> In healthcare and life sciences, we're channeling the unparalleled computing power of quantum technologies for advancements in cancer research and personalized medicine. We have developed a solution that can accurately predict the effectiveness of various drugs on a broad range of cancer cell lines. Published in the oncology journal Cancers MPDI, our research demonstrates that a hybrid quantum-classical neural network, even trained on a small dataset of drugs and cell lines, can predict the most appropriate dosages with superior accuracy versus a solely classical neural network
>
> – FLORIAN NEUKART, CHIEF PRODUCT OFFICER AT TERRA QUANTUM AG

An additional use case of quantum computing and artificial intelligence could be to digitally simulate human biology to virtually test drug variants before human trials. If realized, this application could accelerate early drug discovery and increase new drugs' success rate and safety during human trials.

So while the potential is plentiful, the path to get there is challenging and long.

> People are focusing too much on breakthroughs in single-point energy calculations... I understand why, as it potentially brings significant promise of quantum advantage. But many other calculations such as for binding affinities or molecular dynamics in quantum and chemistry simulation are more relevant from an industrial point of view... To get to the full potential of quantum computing into drug development there are many open questions... we are taking small steps toward this potential, but we might encounter numerous challenges on the way we are not currently aware of.
>
> – MICHAEL STREIF, QUANTUM COMPUTING SCIENTIST AT BOEHRINGER INGELHEIM

> Are we at the state where we have enough physical qubits and good enough error correction to be able to perform calculations greater than classical systems? No. But I do think that quantum computers will have fantastic potential as we continue to industrialize the manufacturing of these systems.
>
> – KEN DURAZZO, VP, DELL RESEARCH

[32] *Deloitte: Measuring the return from pharmaceutical innovation 2022 | Deloitte US*

CRYPTOGRAPHY AND CYBERSECURITY

BCG US$ value creation impact estimate: $40-80bn.

Cybersecurity was the next noted industry from our 2022 report and also received its own category in the BCG report, denoting its importance and impact quantum computing could have on this category.

As a caveat, the use cases in cybersecurity stem from preparing for quantum computing's potential for threatening existing encryption. Thus, the value prediction comes from the potential market opportunity of preparing for this threat.

For example, the upcoming updated cybersecurity standards by the US National Institute of Standards and Technology (NIST), especially targeting critical infrastructure players outlined by the Cybersecurity and Infrastructure Security Agency (CISA) is a response to the potential threat of quantum computing.

> Cybersecurity is huge. Areas such as quantum communications, quantum crypto inventories, crypto agility, and so on: those are some of the main focuses for us.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

OPTIMIZATION, MACHINE LEARNING, AND SIMULATION IN FINANCE

BCG US$ value creation impact estimate: $70-135bn.

The financial industry could enjoy expanded use of quantum computers.

The breadth of quantum computing use cases for financial services covers, for example:

- Portfolio optimization
- Risk management and simulation
- Fraud and money-laundering prevention
- Market simulation

An estimate conducted by Finra analysts predicted that twenty percent of financial institutions in 2023 will have budgeted to enable quantum technologies and their applications in some form.[33] Over the next ten years, according to Deloitte Insights, financial services' spending on quantum computing is expected to increase 230 times, from $80 million to $19 billion.[34]

Experts were divided on the timeline and current usability of quantum in finance. Some highlighted a 1-5% improvement in financial operations from quantum computing today, while others state we are potentially many years away from quantum advantage, especially compared to classical high-powered computing systems.

> In financial services, I think there are so many potential use cases, but I don't think we have applications with clear-cut wall clock performance advantages... quantum computers are significantly slower at individual operations compared to classical systems... we have to look more carefully at other use cases or improve our algorithms further.
>
> – FABIO SANCHES, QUANTUM COMPUTING DIRECTOR AT THE FEDERAL RESERVE

[33] *Finra: Quantum Computing and the Implications for the Securities Industry*
[34] *Deloitte Insights: Industry spending on quantum computing will rise dramatically. Will it pay off?*

OTHER QUANTUM COMPUTING USE CASES

FLIGHT ROUTE AND VEHICLE ROUTING OPTIMIZATION

BCG US$ value creation impact estimate: $70-150bn.

Quantum computing's potential unique processing could enable the optimization of complex infrastructure problems such as identifying optimal delivery routes.

For example, quantum computing could potentially streamline logistics through real-time route optimization and strengthen infrastructure through scenario simulations.

> Every company has a business operation that can be looked at as an optimization problem... exploring the use of quantum for these challenges: logistics, manufacturing, warehouse companies. These are examples of companies... trying to use quantum tech to find a business advantage...
>
> – KEN DURAZZO, VP, DELL RESEARCH

AUTOMATED VEHICLE, AI ALGORITHMS

BCG's US$ value creation impact estimate for autonomous driving is up to $10bn, and AI applications, in general, are over $80bn.

The synergies between quantum computing and artificial intelligence–covered in detail in Theme 4–could improve autonomous driving by saving time, fuel, accidents, and more.

MANUFACTURING AND DESIGN

BCG US$ value creation impact estimate: $60-105bn.

In general manufacturing, but especially for airplanes, automotive, and battery performance, quantum computing could optimize material performance to produce more efficient products through quantum simulation.

A notable example is the potential for quantum computing to expedite the discovery of new materials simulating properties and interactions at the molecular level, which if realized, could significantly improve product performance and manufacturing speed.

> Two use cases seem interesting in quantum computing... the security of communication and cryptography, and... quantum simulation such as generative chemistry, material simulation and discovery.
>
> – QUANTUM RESEARCH MANAGER AT GLOBAL MULTI–INDUSTRY CONGLOMERATE

> In mass production, quantum can provide a lot of value by performing tasks to a high level that would be impossible for classical computers. It can handle far more complex workflows, helping to optimize workflows from the manufacture of goods to their delivery to customers. There is a highly interesting use case for it in supporting eco-friendly steelmaking, streamlining the highly complex analysis of different materials to cut costs and deliver a more scalable, environmentally friendly use case.
>
> – BRAD KIM, CHIEF QUANTUM OFFICER & SENIOR EXECUTIVE VP

COMPUTATIONAL FLUID DYNAMICS

BCG US$ value creation impact estimate for fuel and other liquids optimization in automotive and airplanes: $10-30bn.

Any object that uses fuel and other crucial fluids could be optimized by quantum computing based on dynamic variables and constraints such as supply/demand and weather patterns.

For example, airplanes could increase the efficient usage of fuel based on micro changes in wind speeds by utilizing quantum computation.

CLEAN ENERGY INFRASTRUCTURE AND CONVERSION

BCG US$ value creation impact estimate for solar conversion: $10-30bn.

Quantum computing could have a notable positive impact on the output of solar and wind farms. Similar to material optimization and simulation, quantum computing could improve the design of solar panels and wind turbines, potentially increasing their energy conversion.

Quantum algorithms could also optimize energy systems output based on dynamic variables such as supply, demand, storage, and distribution.

THE IMPORTANCE OF PRIMITIVES

These represent only a sample of the potential applications. One of the critical themes that came out of our interviews was the challenge in really testing use cases on early stage quantum computers, and linked to this, the need for more algorithmic primitives.

> Even if we did have a 10 million qubit functional quantum computer today we wouldn't use it because we don't have the algorithms. I think algorithm development is focusing too much on NISQ algorithms and not enough on FTQC algorithms.
>
> If we could see more algorithmic primitives in FTQC or make these faster, that would be super exciting for me. Right now, there are only four or five useful primitives. Take quantum phase estimation for quantum chemistry in an industrial setting as an example, if someone could bring down this algorithm from taking days to seconds then that would mean a significant incentive to use quantum computing as a business case.
>
> – MICHAEL STREIF, QUANTUM COMPUTING SCIENTIST AT BOEHRINGER INGELHEIM

While quantum computing's use cases are maturing, we are still too early to witness any substantial business use: we need to make quantum computing more reliable and practical through algorithm primitives.

Quantum Computing's Growing Industry Use Cases

Across industries, quantum computing advanced its significant promise as enterprise end-users continued to invest and focus on testing use cases, with examples such as BMW, HSBC, Sony, Siemens, Moderna, and Microsoft.

Healthcare, cryptography, and finance continue to be the leading areas that hold significant potential from quantum computing either impacting or enabling prospects that more and more companies pursue.

Despite challenges remaining—including costs, hardware reliability, and talent shortages—they are being ameliorated and addressed, enabling advanced simulation, expanded optimization, improved machine learning, and a growing call to respond to the cybersecurity threat that quantum computing potentially ensues.

> To unlock quantum computing's transformative potential, we need deep integration of quantum processor units, extending from the web interface all the way through to physical co-location in HPC infrastructure. The significant value of hybrid quantum comes through the cloud, with one unified platform that runs on this mix of native quantum hardware, software and classical computing. The cloud levels the playing field, ensuring that anyone, from an individual researcher and a start-up to a thriving enterprise, can tap into the benefits of quantum hardware and software through their existing cloud set-up. They don't need to wait; instead, they can start experimenting with the technologies and tackling today's biggest challenges from day one.
>
> A quantum gold rush is underway. It is up to the quantum industry to make sure that users have the shovels and machinery to make it a reality.
>
> – GEORGE GESEK, CHIEF TECHNOLOGY OFFICER AND CO-FOUNDER OF QMWARE

2023 marked clear indicators that early adopters and innovators in quantum computing are starting to improve their understanding of and path to the potential opportunity.

Conclusion

The report continues and elaborates on the insights gained in the 2022 State of Quantum report. But where the last report focused on a broader survey, this year we provided nuance through personalized perspectives from thought leaders in enterprise end-users of quantum.

Predictions made in 2022 of the emergence of dedicated quantum roles and teams came to fruition from across leading corporations, while the three focus areas of cybersecurity, financial services, and healthcare continued to mature and show some of the earliest promise.

Yet, nuances were revealed, as quantum teams are diverting their attention to hybrid computing paradigms in order to “bridge the gap”, and the integration of generative AI from its surge in hype. Not to mention the core algorithms and language to operate quantum computers are fundamentally different from its classical cousin and an area that must be further explored.

> We are still in the Electronic Numerical Integrator and Computer... days of quantum computing... Today’s quantum systems are not programmed and do not behave like classical systems. I believe that we are going to get there eventually, but it will be a journey... companies are going to have to spend more time learning the paradigms of quantum systems and developing the workforce to take full advantage of these nascent systems.
>
> – KEN DURAZZO, VP, DELL RESEARCH

THEME 1

Investment Landscape Conclusion

The quantum technology sector's investment in 2023 reflects a cautious recalibration back to 2019/2020 figures, with venture capital retreating by approximately 50% from the previous year's zenith.

However, the downturn was largely driven by the United States, with an 80% reduction, as the APAC and EMEA regions demonstrated greater resilience. One of the reasons for this demonstrable resilience was the national investment to create strong sovereign capabilities.

In a parallel upswing, more than 30 active governments have announced investment commitments more than $40 billion over a period of 10 years, dwarfing private funding by conservative estimates.

Thus, with the advent of a broader deep technology downturn in VC investment, whispers of a 'quantum winter' are in fact a recalibration in governments' critical role in supporting longer termed technologies such as quantum before it potentially can achieve commercial advantage with its growing practical use cases.

THEME 2

Quantum Computer Deployments and National Centers Conclusion

As investment pivoted to governmental funding, so did we witness deployments of practical quantum computers in national centers across North America, Europe, and beyond. This is a development that shows continued progress in exploring quantum computing in a research setting with key collaborations with startups and the broader industry.

These centers serve as beacons of progress across quantum computing modalities, hosting different types of quantum computers, ranging from cryogenic systems to optical setups.

As quantum computing remains largely theoretical with research problems being tackled, it is a crucial step in maturing its potential in solving larger commercial problems demanded by end-users.

THEME 3

Quantum and AI Conclusion

2023 also marked the interplay between artificial intelligence and quantum technology as increasingly pertinent, with AI's surging prominence competing for attention and resources.

Yet the convergence of these two emerging technologies holds the promise for potentially transformative combinations.

The complementary nature of quantum computing to AI as a facilitator of advanced machine learning and in overcoming technical barriers are points of ongoing research and development despite it still being theoretical.

Quantum computing and generative AI are not adversarial technologies, but complementary and should be treated as such.

THEME 4

Use Cases Conclusion

For industry use cases, the advancement of quantum technologies continues unabated, supported by a rising number of enterprise end-users investigating research problems and indications of value despite them being several years down the line.

> I believe the first quantum advantage will occur in the following order: math problems, physics simulations, chemistry, followed by a significant gap before optimization and machine learning. For the latter, to get execution times faster than GPUs and other HPC systems is extremely difficult.
>
> – MICHAEL STREIF, QUANTUM COMPUTING SCIENTIST AT BOEHRINGER INGELHEIM

Thus, echoing the State of Quantum 2022 report, healthcare, cybersecurity, and finance remain frontrunners in their potential and development to harness or bar against quantum computing's potential with varying timelines and development paths.

Albeit existing challenges such as hardware reliability and talent shortages persist, the maturation of quantum-safe encryption, drug discovery simulations, and financial optimization models demonstrate areas where quantum's looming practical impact begins to crystallize with a level-headed perspective.

> We need to have realistic expectations about what innovation is... A fitting analogy is the invention of the shopping cart where the inventor was shocked to witness that no one wanted to use it... he ended up paying actors to stroll around the grocery store with a shopping cart until more customers started to adopt it... if the shopping cart had a hard time getting adopted... quantum will have a harder time. We need to adjust our expectations, prepare for ups and downs; disappointments and successes.
>
> – QUANTUM RESEARCH MANAGER AT GLOBAL MULTI–INDUSTRY CONGLOMERATE

Outlook for 2024 and beyond

The consensus we found from interviews of quantum end-user stakeholders is that current business needs are supplied from quantum-inspired solutions and traditional HPC systems aka “Hybrid”.

Universities will also start to develop dedicated quantum computing and technology programs. For one, to satisfy the concerns of industry in locating necessary quantum talent, but also to advance quantum technology’s progression.

While 2024 could be the year where expectations for ‘pure’ quantum systems are measured to fit its timeline for quantum advantage. An integral part of achieving this is an increased transparency from quantum technology roadmaps and the meeting of their milestones.

> We will see more universities start to build quantum programs in computer science... which focus on workforce development... We are on the precipice of something big in quantum– we’re likely to see some very unique ways to derive advantage from combining the computational capabilities of both classical and quantum systems...
>
> – KEN DURAZZO, VP, DELL RESEARCH

> I look forward to the quantum industry becoming more transparent such as published development roadmaps and its progression... it will help the broader quantum industry and end-users to gain more clarity on the timeline of quantum computing. We don’t want quantum to become the new nuclear fusion and continually be 50 years out.
>
> – QUANTUM RESEARCH MANAGER AT GLOBAL MULTI–INDUSTRY CONGLOMERATE

Besides these general observations, five preliminary predictions below are made for 2024.

1. ON-PREM VERSUS CLOUD ACCESS: THE DATA SECURITY COMPLICATION

Peering into 2024, as quantum technologies progress from minor research problems to larger use cases, end-users across industries will grapple with regulatory requirements.

One challenge that has been flying under the radar is the importance for end-users to access on-premise quantum computing over the cloud, due to data security and privacy regulations. This is especially predicted in critical infrastructure players such as financial services, national defense, and healthcare.

> Onboarding and embedding new types of technology takes time and financial investment... many nuances will come into play, from verification, data security to model error... If circuit optimizers use black box methods, I don't think we will be able to use it in the business, because we cannot prove model validation.
>
> For applications that require physical deployment, it will take years to actually be able to adopt quantum because no one wants to adopt on-premises quantum computing due to its high costs and complexity, which has to be done due to data security.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

> There are organizations that would not feel comfortable with accessing quantum computing through the cloud as it potentially integrates with other services considering data security. I think we need more education around how this is going to work...
>
> – FABIO SANCHES, QUANTUM COMPUTING DIRECTOR AT THE FEDERAL RESERVE

2. QUANTUM COMPUTING'S COST

Another significant barrier going into 2024 will be the accessibility of quantum computing for end-users, considering 'cost per useful hour.'

As a consequence, most quantum computing projects are smaller in scope and largely driven in national quantum computing centers as opposed to scaled enterprise use cases.

> For 2024, the expectation is now to show a roadmap to revenue... We've shown that quantum works and that we can scale it, but until we can demonstrate a tangible delivery, how much money a quantum algorithm has saved or made us, the interest and investment in quantum has a ceiling.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

> Cost of quantum can be quite prohibitive and unsustainable... one hour on a quantum computer costs between 100 to 300 times more than a top GPU per hour. If you think about... the 'dollar per useful unit of compute' then one hour on the average quantum computer is significantly less useful than an hour on a high performance GPU system. This already can limit experimentation... [and] ...be a major consideration for future generations of hardware...
>
> – FABIO SANCHES, QUANTUM COMPUTING DIRECTOR AT THE FEDERAL RESERVE

A caveat does lie in the expectation and time horizon of corporations as industries operating on longer termed periods, such as pharmaceuticals in drug development, generally adopt a more relaxed view of quantum computing's cost per useful hour.

> I was surprised... the main blocker was the cost of using quantum hardware... that's not the main reason why we don't use quantum hardware. We don't use quantum hardware because it does not give an advantage over simulating chemical systems on today's classical computers.
>
> For us, a timeline between five to ten years is not a problem, as the average time to develop a new drug is ten to twelve years.
>
> – MICHAEL STREIF, QUANTUM COMPUTING SCIENTIST AT BOEHRINGER INGELHEIM

3. MORE TEAMS IN ORGANIZATIONS WILL GET ‘QUANTUM READY’

An increasing number of organizations are looking into developing their expertise and workforce in quantum technologies despite the long-term perspective the potential technology necessitates.

> One way to prepare your workforce to get quantum-ready, is to start looking at business optimization problems... these types of problems can be formatted into Quadratic Unconstrained Binary Optimization (QUBO) formats. You can use QUBOs with classical solvers, then quantum annealing technology, and later full-scale quantum systems... These are the types of small actions, that will prepare your team to be ‘quantum-ready’ in the future.’
>
> – KEN DURAZZO, VP, DELL RESEARCH

> On the finance side, you see more dedicated quantum teams, some in pharma as well. But you see that shifting to HPC [High-Powered Computing], because I think what we’re finding there is an industry need. We realized there was a big gap, like accelerated computing.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

Recruiting and hiring quantum-specialized talent will remain a significant challenge for corporations in 2024.

> Quantum is still a very specific niche, which makes hiring the right talent very challenging. With quantum computing, there just isn’t that comprehensive talent pipeline yet. Similarly, retraining or upskilling your current workforce is also difficult, but this makes internal nurturing talent a bigger imperative.
>
> – TAHMID QUDDUS ISLAM, QUANTUM TECHNOLOGIES LEAD AT CITI GLOBAL INSIGHTS

4. THE EXCITED STATE OF QUANTUM

A consensus persists that quantum advantage and its practical utilization are between five to twenty years away. Thus, between now and then, keeping interest alive in quantum will be a necessity and a potentially continuous challenge.

> I think it is a bit concerning that quantum companies and quantum efforts are being turned into IPOs. The big names will be able to cushion the mood of the stock market and bring quantum computing from potential to practicality. But I am concerned that without solid corporate or government backing, the quantum efforts listed on the stock market may have a challenge in weathering economic headwinds.
>
> We need to be prepared for these types of shocks and tactics to continue the interest in quantum solutions.
>
> – QUANTUM RESEARCH MANAGER AT GLOBAL MULTI–INDUSTRY CONGLOMERATE

5. HYBRID SOLUTIONS NOW AND PURE QUANTUM COMPUTING LATER

Stemming from the emerging need to deliver, or allude to, practical value achieved by quantum computing, some end-users have identified a disconnect between their need to see results and quantum suppliers' focus on 'pure' quantum systems.

Current quantum-hybrid and HPC solutions are delivering value to some end-users' needs, providing opportunity spaces for existing quantum vendors. In fact, end-users often categorize 'pure' quantum and quantum-inspired in the same bracket and budget.

> In the short to mid term, I believe that by focusing on hybrid classical-quantum systems we are likely to see some breakthroughs in computational advantage for specific applications.
>
> – KEN DURAZZO, VP, DELL RESEARCH

And while it presents current value-generating opportunities, some quantum suppliers remain focused on 'pure' quantum systems which could be years away from delivering practical business use cases.

Consequently, going into 2024, we could see this disconnect crystalize into more quantum players across the value chain expanding into 'quantum-inspired' systems underpinned by traditional chips gaining value now while building a bridge to future 'pure' quantum computers.

> Alternative quantum-inspired methods for NISQ in the quantum industry are often dismissed. You want to achieve results on quantum computers, but in terms of generating revenue, alternative methods like annealing, Ising solvers, and photonics may be the necessary paths to produce these results.
>
> – MEKENA METCALF, SENIOR QUANTUM COMPUTING RESEARCH SCIENTIST AT HSBC

> What I have found helpful is creating a larger umbrella of success, so rather than just talking about quantum computing, you incorporate quantum sensing, quantum networking, quantum communication... these areas in quantum can have different lead times and thus investing in multiple areas can mean practical value is generated quicker.
>
> – QUANTUM RESEARCH MANAGER AT GLOBAL MULTI–INDUSTRY CONGLOMERATE

While it is likely that further collaboration and partnerships will merge quantum-inspired, hybrid solutions with prospective 'pure' quantum systems.

> It is crucial to stress the importance of collaborations to benefit all the stakeholders. We need to be working more together than apart, and that means not only different quantum end-users but also different hardware manufacturers and quantum suppliers.
>
> – ALEXEY GALDA, ASSOCIATE SCIENTIFIC DIRECTOR, QUANTUM ALGORITHMS AND APPLICATIONS AT MODERNA

The quantum computing and HPC deployments in centers across North America, Europe, and beyond, signify the immense potential of quantum computation and its developing use cases. While it further promotes the current value HPC and other quantum-inspired solutions can provide end-users now.

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ABOUT IQM QUANTUM COMPUTERS

IQM is the global leader in building quantum computers. IQM provides on-premises quantum computers for supercomputing centers and research labs and offers full access to its hardware. For industrial customers, IQM delivers quantum advantage through a unique application-specific, co-design approach.

IQM's commercial quantum computers include Finland's first commercial 50-qubit quantum computer with VTT, IQM-led consortium's (Q-Exa) HPC quantum accelerator in Germany, and IQM processors will also be used in the first quantum accelerator in Spain.

IQM has over 300 employees with offices in Espoo (Finland), Munich (Germany), Madrid (Spain), Paris (France), Singapore, and Palo Alto (CA, US).

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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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