Quantum computing technologies roadmap (HW/SW) and assessment of emergent and promising quantum computing technologies 2023

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1 Introduction

Expectations on the outcome of the race towards quantum computing are still very high, and analysts show that the trend is not slowing down. According to the World Economic Forum, **public investments** in quantum technologies, including quantum computing, increased by **$3.2 billion in 2021** alone, and by **over $5.5 billion in the past decade**[1]. These figures are probably lower than the reality, as not all of these investments are publicly disclosed. For several years, China and the European Union, with Germany leading, have announced the most public funding for quantum technologies[2][3][4][5]. International Data Cooperation (IDC) projects that **investments in the quantum computing market will reach nearly $16.4 billion by the end of 2027**[6]. The same analysts expect **customer spending on quantum computing to reach $7.6 billion by 2027**.

The various academic and industrial players involved in hybrid high performance computing and quantum computing (HPC-QC) are showing **progress** that supports this enthusiasm. However, it's still very **hard to decipher HPC-QC-related announcements**. The risk of overselling or misinterpretation is very high, as much of this information is exploratory and needs to be carefully analyzed by a handful of experts to make it available to a wider audience. At this stage in the history of quantum computing, **fact-checking** by experts is crucial. Scott Aaronson, in the US, and Olivier Ezratty, in Europe, are good examples of this fact-checking initiatives.

Also, **most players in the field are only beginning to consider the integration of quantum computing and high-performance computing.** These two worlds have long been clearly separated and are still in the early stages of their integration, so many announcements still refer exclusively to quantum computing. Nevertheless, it's interesting to see that more and more companies are attending HPC conventions such as ISC23 (Hamburg, Germany, May 2023) and SC23 (Denver, TX, November 2023), with panel sessions and conferences that address the topic of HPC-QC integration.

2 Description of Activities

1. HPC-QCS technological orientations for 2023 and early 2024

a. Nobel Prize 2023 in Chemistry

After the 2022 Nobel Prize in Physics, quantum technologies were in the spotlight again in 2023 with the **Nobel Prize in Chemistry**, awarded to Alexei Lekimov, Moungi Bawendi and Louis E. Brus, for their work on the discovery and **synthesis of quantum dots** (see Figure 1). With wide applications in, for example, imaging, sensing or flexible electronics, quantum dots also the core component of a specific

[1] https://www.weforum.org/publications/state-of-quantum-computing-building-a-quantum-economy/
[2] https://www.mckinsey.com/~/media/mckinsey/featured%20insights/the%20rise%20of%20quantum%20computing/quantum%20technology%20monitor/2020/mckinsey-quantum-technology-monitor-202012.pdf
[3] https://www.mckinsey.com/~/media/mckinsey/featured%20insights/the%20rise%20of%20quantum%20computing/quantum%20technology%20monitor/2021/mckinsey-quantum-technology-monitor-202109.pdf
[4] https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20computing%20funding%20remains%20strong%20but%20talent%20gap%20raises%20concern/quantum-technology-monitor.pdf
[5] https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20technology%20sees%20record%20investments%20progress%20on%20talent%20gap/quantum-technology-monitor-april-2023.pdf
[6] https://www.idc.com/getdoc.jsp?containerId=prUS51160823

qubit technology: single photon light sources. A Nobel Prize awarded again for a quantum technology that the field has a solid scientific foundation and, as a bonus, gives good media coverage.

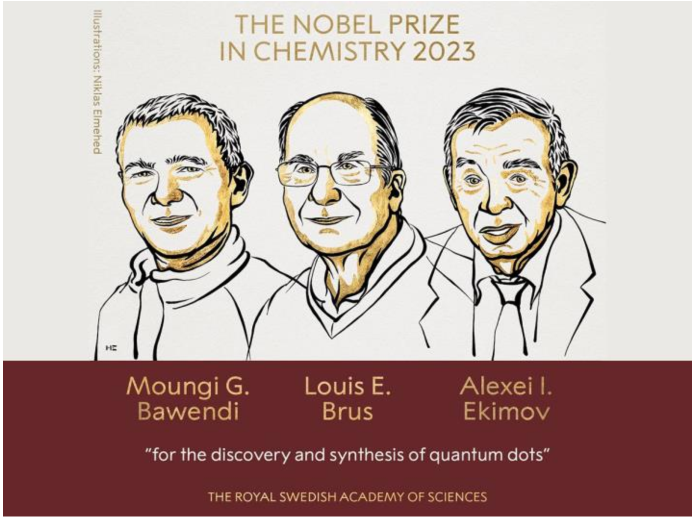

Figure 1 - Presentation of the three Chemistry Nobel Prize laureates of 2023 : Moungi G. Bawendi, Louis E. Brus and Alexei I. Ekimov

b. Scalability

Even if there has been an evolution in the metrics considered to compare quantum platforms, the number of qubits is still a broadly observed quantity. Nevertheless, new approaches carried out by different constructors tend to shift the mentality away from this focus.

Emerged and presented in last year's report, the strategy of scale-up scale-out continued in 2023. **IBM** followed the strategy, releasing at the end of the year **a 1,000-plus qubit QPU**[7] as well as **a modular architecture comprising "only" 133 qubits** and aiming for QPUs interconnection to grow the system size[8]. This important threshold has to be reached in order to run error correction algorithms efficiently. The scale-out strategy seems to also have found its limits for the trapped-ion-based technology. IonQ anticipates a practical size limit in their QPUs and plans to build multicore QPUs based on the notion of the Reconfigurable Multicore Quantum Architecture (RMQA) in which multiple ion chains are manipulated to dynamically form quantum computing cores[9]. However, the scale-up strategy still has its defendants, especially in the world of neutral atoms, promoted by vendors such as **Atom Computing** announcing a **1,000-plus qubit quantum computer** at the end of 2023[10] or **QuEra** announcing in January 2024 their goal of a **10,000-qubit system** in 3 years[11].

c. Qubit robustness

2023 has been a year of progress in qubit accuracy. **IBM** launched its **Heron chip** aiming for **99.99% two-qubit gates** and included in their roadmap the integration of error mitigated execution in 2024 to demonstrate quantum utility[12]. Moreover, 2023 also saw significant improvements in the world of fault tolerant quantum computing. Starting in February, **Google**'s research team showed theoretically that

[7] https://doi.org/10.1038/d41586-023-03854-1
[8] https://research.ibm.com/blog/quantum-roadmap-2033
[9] https://ionq.com/resources/reconfigurable-multicore-quantum-architecture
[10] https://atom-computing.com/quantum-startup-atom-computing-first-to-exceed-1000-qubits/
[11] https://www.hpcwire.com/2024/01/09/quera-debuts-3-year-roadmap-to-10000-physical-and-100-logical-qubits/
[12] https://newsroom.ibm.com/2023-12-04-IBM-Debuts-Next-Generation-Quantum-Processor-IBM-Quantum-System-Two,-Extends-Roadmap-to-Advance-Era-of-Quantum-Utility

a **17-qubit system** would be **resilient to one error** and a **49-qubit system** would be **resilient to two simultaneous ones**[13], proving once again the necessity of scaling up systems for error-corrected applications. Continuing with active error correction, **IBM** published a new error correction scheme **reducing by an order of magnitude** the number of **qubits necessary** for error-corrected applications[14]. This discovery helped refine IBM's roadmap for the next 10 years, putting more effort into developing modular interconnected reliable chips that could execute this new scheme. Hardware wise, **Amazon** presented a **1-qubit hardware corrected chip** using the cat qubit technology supposed to **reduce the error rate by 100** (unfortunately, no element of comparison was provided)[15]. Finally, **QuERA** and a team of **Harvard researchers** demonstrated a **48 logical qubits system** based on **QuERA's 250-physical-qubits** system reaching an important milestone on the way for fault-tolerant quantum computing[16].

Moreover, a major issue about assessing the quality of quantum systems and more specifically the accuracy of quantum bits needs to be considered, namely **benchmarking**.

In recent years, numerous benchmarking metrics have emerged. Most of these (more than a 1,000) are summarized on the website **metriq**[17] where the wide world can navigate to evaluate the quality of quantum systems. Therefore, many benchmarking initiatives have emerged worldwide. The main challenge of such activity is to be able to evaluate the relative performance of a quantum system without losing generality. To do so, the metrics need to be **general**, i.e., applicable on any quantum platform, **useful**, meaning they represent a "real-world" problem, and above all **scalable**, adaptable and exptensiblee to evolving technologies.

In the USA, the latter approach was followed by the US Defense Advanced Research Projects Agency (**DARPA**). In 2022, DARPA selected **Raytheon BBN ($2.9 millions)**, **the University of Southern California (USC, $4.1 millions)**, and a team of five organizations including **Aalto University**, **IonQ**, **University of Technology Sydney**, **University of Texas** in Dallas, and **Zapata Computing**, to work on research projects and find new benchmark strategies. In 2023, they renewed their confidence in the same consortium to develop, in a second phase, **BenchQ**[18]. BenchQ is an **open-source** tool for benchmarking quantum computing applications. The focus will now be on the improvement of the tool with new use-cases as well as on its dissemination in the quantum computing community.

In France, in September 2023, the **BACQ (Benchmark Applicatif des Calculateurs Quantiques)**[19] project was launched. Part of the **MetriQs-France** project, a national project on measurements, standards and evaluation of quantum technologies, BACQ is aiming to develop a long-lasting, objective and widely shared common benchmark reference focusing on applicative algorithms. The project gathers a wide number of French vendors mingling national research institutes, industrials as well as start-ups and normalization agencies.

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[13] https://doi.org/10.1038/s41586-022-05434-1
[14] https://doi.org/10.48550/arXiv.2308.07915
[15] https://www.hpcwire.com/2023/11/28/reinvent-2023-aws-talks-a-little-quantum-showcases-error-correction-progress/
[16] https://doi.org/10.1038/s41586-023-06481-y
[17] https://metriq.info/
[18] https://pypi.org/project/benchq/, https://www.hpcwire.com/off-the-wire/zapata-ai-earns-second-darpa-award-for-quantum-benchmarking/, https://quantumcomputingreport.com/zapata-introduces-benchq-an-open-source-tool-for-quantum-computing-resource-estimation-and-benchmarking/
[19] https://www.usinenouvelle.com/article/notre-benchmark-des-ordinateurs-quantiques-sera-oriente-applications-et-fera-sens-pour-l-utilisateur-final-assure-frederic-barbaresco-de-thales.N2131411

2. Public initiatives and funding

QURECA summarized global efforts in 2023 leading to research and innovation in quantum science and technology, which currently represent $38.6 billion in global investments (see Figure 2). Public initiatives and funding are described in the text following Figure 2.

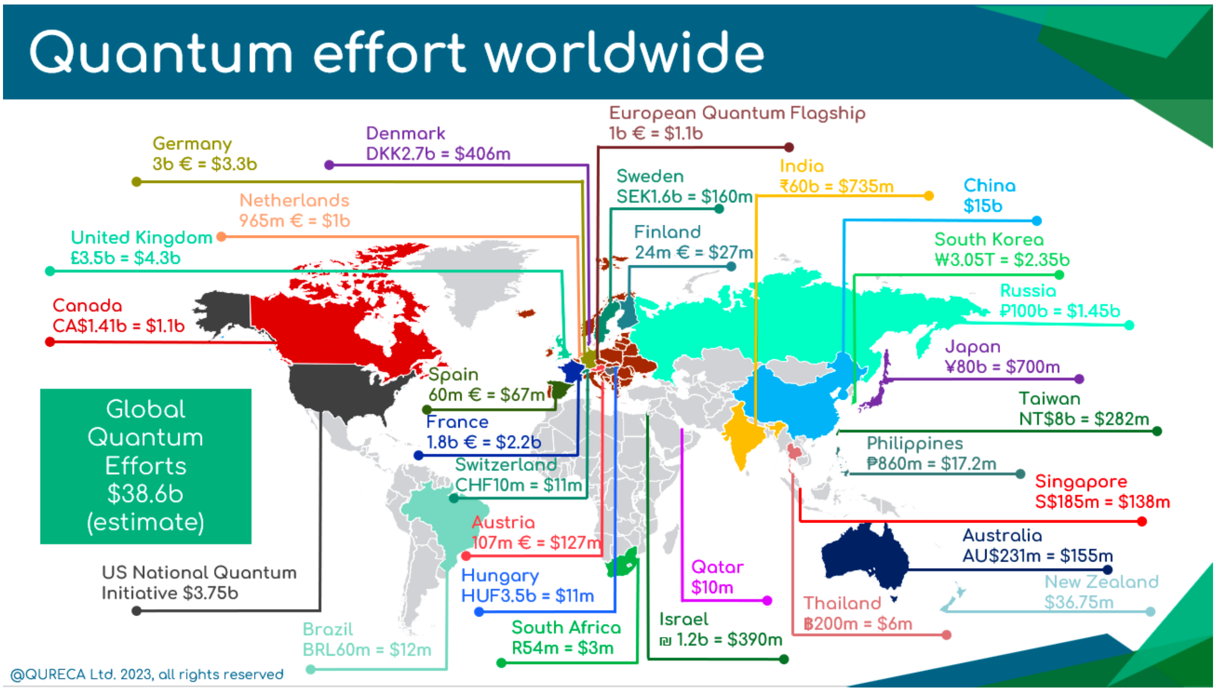

Figure 2 - Overview of funding for quantum initiatives worldwide according to QURECA[20]

a. America

With the launch of **Canadian national quantum strategy**[21] by the **Minister of Innovation, Science and Industry** in January 2023, Canada has strengthened its position as one of the world leaders in the development of quantum technology. The plan with **$360 million** committed in 2021 Budget will have three pillars: a **research program ($141 millions)** aiming to support theoretical and applied quantum sciences for the development of innovations; an investment of **$45 million** to retain and attract **technical experts** on the national territory; a **commercialization plan ($161 millions)** aiming on pushing research solutions as commercial products for the quantum industry.

The united-States government supported its **National Quantum Initiative (NQI)** with an additional investment of **$1.46 billion**, bringing the total investment of the program to **$3.75 billion**. Moreover, in November, the US government announced the National Quantum Initiative **Reauthorization act**[22] to establish **three centers for advanced research in Quantum Sensing**, measurement and engineering. The clear aim is to strengthen the American workforce around quantum computing and to develop the American strategy of cooperative research to ensure its competitiveness against China and Russia.

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[20] https://qureca.com/overview-of-quantum-initiatives-worldwide-2023/, https://www.hpcwire.com/off-the-wire/hyperion-research-pins-2023-global-quantum-computing-market-at-848m-with-22-1-cagr-for-2024/

[21] https://www.newswire.ca/news-releases/government-of-canada-launches-national-quantum-strategy-to-create-jobs-and-advance-quantum-technologies-869929816.html

[22] https://science.house.gov/2023/11/the-national-quantum-initiative-reauthorization-act, https://science.house.gov/2023/11/support-grows-for-the-national-quantum-initiative-reauthorization-act

b. Europe

Published in March 2023, the **United Kingdom** proposed their **new national quantum strategy**[23], with a **£2.5 billion investment** over ten years starting from 2024. This sustains the will of the UK government to be a quantum enabled economy by 2024 and among the world-leaders in quantum sciences and engineering by 2034. The strategy focuses on many aspects with an emphasis on the adoption and use of quantum technology in the UK economy and national security along with the development of local quantum industry. One of the aims is to have by 2035 a quantum computer with a demonstration of quantum advantage based on UK quantum technologies.

On its side, the **Irish government** published in November 2023 the **national quantum strategy** Quantum 2030[24]. It highlights the necessity of funding in the Irish ecosystem around several pillars: development of quantum technologies research, recruitment and training of quantum engineering talents, development of national and international collaborations, and economic competitiveness through the support of innovation and entrepreneurship. However, for now, no announcement of any public investment has been made.

In August 2023, the document "**Key Performance Indicators for Quantum Technologies in Europe**" was published[25]. The document is a recommendation of the Strategic Advisory Board of the European Quantum Flagship and the European Commission to monitor and evaluate the progress of quantum technologies, including quantum computing and quantum simulation, in Europe. The Key Performance Indicators (KPIs) are formulated to have a perspective towards 2030 and reflect overall research and innovation goals as set forth in the Strategic Research and Industry Agenda[26].

The **European High Performance Computing Joint Undertaking (EuroHPC JU)** followed its strategy for the installation of quantum computers with different qubit technologies at 6 sites across the European Union (EU), which have been selected in 2022. They launched the **first procurement tender** for a trapped ion machine in **PSNC** (Poland) in October 2023[27], and for the extension of a superconducting quantum computer in **LRZ** (Germany) in November 2023[28]. The tender for a photonic machine hosted at **GENCI-CEA** (France) has been launched In January 2024[29].

Locally, several investment plans have been launched or committed in different countries. That's the case for **Switzerland**, which invested **$11 millions** in the **Swiss Quantum Initiative**[30] in 2023/2024 to strengthen its position in the European quantum technology ecosystem. More significantly, the **German federal government** announced a **$3-billion investment plan** over 3 years to develop and deploy a universal **100-qubit quantum computer** by 2026 with a near term extension to **500 qubits**[31].

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[23] https://www.gov.uk/government/publications/national-quantum-strategy/national-quantum-strategy-accessible-webpage
[24] https://www.innovationnewsnetwork.com/quantum-2030-ireland-launches-first-national-strategy-for-quantum-technologies/40144/
[25] https://qt.eu/working-groups/key-performance-indicators
[26] 2022 Strategic Research and Industry Agenda: https://qt.eu/media/pdf/Quantum-Flagship_SRIA_2022.pdf
[27] https://www.hpcwire.com/off-the-wire/eurohpc-ju-launches-procurement-for-euroqcs-poland/
[28] https://www.hpcwire.com/off-the-wire/eurohpc-ju-launches-procurement-for-a-new-quantum-computer-in-germany/
[29] https://eurohpc-ju.europa.eu/eurohpc-ju-launches-procurement-new-quantum-computer-france-2024-01-30_en
[30] https://www.sbfi.admin.ch/sbfi/fr/home/recherche-et-innovation/la-recherche-et-linnovation-en-suisse/sqi.html#:~:text=La%20Conf%C3%A9d%C3%A9ration%20met%20%C3%A0%20disposition,les%20%C3%A9tablissements%20d'enseignement%20sup%C3%A9rieur
[31] https://thequantuminsider.com/2023/05/03/germany-announces-3-billion-euro-action-plan-for-a-universal-quantum-computer/

The announcement highlighted again the necessity for Germany to secure and expand its sovereignty in quantum technologies. Moreover, it emphasized that quantum computing is a key enabler for a world-leading German industry, giving the example of drug discovery.

c. Middle East and Africa

In the **United Arab Emirates**, the **University of Abu Dhabi,** together with the **Vernewell group**, has inaugurated a new **quantum laboratory**[32] in Abu Dhabi. The aim of the laboratory is the creation of a collaborative hub for students, researchers and experts in the field, working as an incubator to stimulate the creation of new innovative solutions in parallel to the development of industrialization processes of quantum technologies.

Early November, the **Hamad bin Khalifa University (HBKU)** partnered with the Canadian photonic specialist company **Xanadu** to train and educate a quantum-ready workforce in **Qatar**. This partnership is the first international partnership of the **Qatar Center for Quantum Computing (QC2)[33]** launched in mid 2022 and demonstrates Qatar's commitment to position itself as an inescapable player in this field in the Middle-East.

d. Asia

Approved in April 2023, **India** began the race for quantum computing with an investment of **about $735 million**[34] for an eight-year program, and so became the seventh country with a national quantum strategy. The mission targets five different sectors such as the development of high sensitivity magnetometers and atomic clocks for communication and navigation or satellite based secured quantum communication. It also emphasizes the development of new material design and synthesis such as semiconductor and superconductor structures. Moreover, it aims for the development of NISQ quantum computers with **targeted 1,000 physical qubits** in 2031, thereby focusing on superconducting and photonic technologies. The mission also includes the development of thematic Hubs in academic and national R&D institutes in quantum computing, communication, sensing and material sciences focusing on theoretical and applied research. The global goal of the mission is to benefit various sectors and to place India as an indisputable player in the race for quantum computing.

In June 2023, a **Memorandum of Understanding (MoU)** was signed between **South Korea's Ministry of Science, Information and Communication Technology (ICT)** and **IonQ[35]** to promote and develop the creation of local ecosystems with a clear aim of quantum technology education directed to Korean professionals and using IonQ resources. This MoU is signed in the context of the South Korean strategy for quantum computing aiming to turn the Korean economy into a quantum-centered economy by 2030.

On its side, **China** didn't expand or announce anything concerning its national quantum strategy. However, the **shut-down of Alibaba quantum research center**[36] can be seen as concerning news. The will to focus on AI instead of quantum with the withdrawal of a **$15 million** 6-year project of a major

[32] https://www.zawya.com/en/press-release/companies-news/abu-dhabi-university-and-vernewell-group-inaugurate-the-first-academic-institution-world-class-quantum-lab-in-abu-dhabi-s8wehfwt
[33] https://www.hpcwire.com/off-the-wire/xanadu-and-hamad-bin-khalifa-university-partner-to-develop-a-quantum-workforce-in-qatar/
[34] https://www.iotworldtoday.com/industry/india-launches-735m-national-quantum-mission
[35] https://www.hpcwire.com/off-the-wire/ionq-signs-agreement-with-south-koreas-ministry-of-science-and-ict-to-cultivate-regional-quantum-computing-ecosystem/
[36] https://www.reuters.com/technology/alibabas-research-arm-shuts-quantum-computing-lab-amid-restructuring-2023-11-27/

company is not a good sign for the development of the Chinese quantum ecosystem. Fortunately, not everything is lost as the equipment was given to Zhejiang University.

e. Australia

In May 2023, the **Australian government** launched its **quantum national strategy** based on a wide consultation conducted in 2022[37]. Divided in 5 different themes the aim is to create a large sovereign industry by 2030. The Australian government forged his will to invest in the connection and the growth of the quantum ecosystem to compete with the world leaders. Even if no announcement about the investment amount has been made, the plan will inscribe itself in the **$15 billion National Reconstruction Fund (NRF)** meant to support, diversify and transform Australia's industry. This strategy focuses on the creation of new quantum infrastructures, aiming to develop the world's first error-corrected quantum computer. The strategy also emphasizes its will to be an active participant in the discussion about **standardization and normalization** worldwide, but also to develop a regulatory framework nationwide to protect national companies' economic interests. As part of this need for standardization, a highlight is put on the ethical development of the field in order to ensure prosperity while safeguarding national well-being via regulation.

3. Main industry highlights

The December 2023 version of the quantum sunburst diagram, or qubit wheel, by Michel Kurek, CEO of France Multiverse Computing, provides a granular breakdown of global organizations (companies of all sizes, universities, RTO…) and their R&D efforts across various qubit modalities (see Figure 3)[38]. In 2023, only a handful of new players have entered the scene.

[37] https://www.industry.gov.au/publications/national-quantum-strategy

[38] https://www.linkedin.com/posts/michelkurek_quantum-quantumcomputing-quantumcomputer-activity-7140621985566318593-jU9Q/

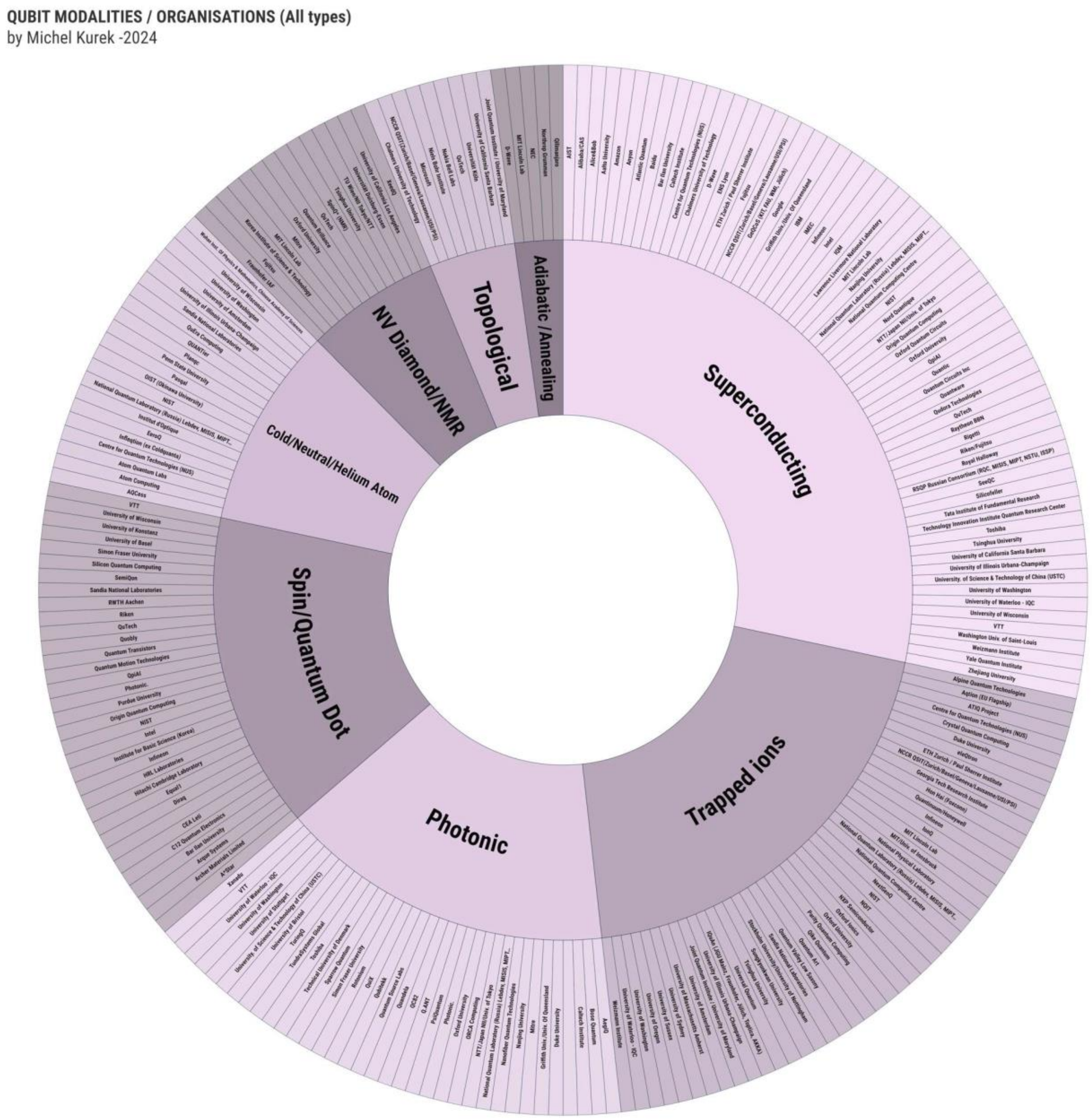

FIgure 3 – Sunburst diagram of global organizations with R&D efforts across the various qubit technologies, Michel Kurek 2024

a. QPU providers

A high-level overview of the landscape of quantum computing companies for the end of 2023, and into 2024 is given by The Quantum Insider[39]. In what follows, the 2023 achievements of the companies are described and grouped according to the various qubit technologies.

i. Superconducting qubits

Many research groups and companies are working on superconducting qubits. Worldwide more than 20 private companies are active in the field of superconducting qubits. A selection is listed in Table 1.

[39] https://thequantuminsider.com/2023/12/29/quantum-computing-companies/

company	country	computing technique	comments
ANYON	Canada	Gate-based	Two systems delivered in 2022 : one to Canadian Defense R&D and the second to an HPC center
ATLANTIC QUANTUM	United Kingdom	Gate-based	Working since November 2023 on the connection of two corrected qubits. Released a QPU control software toolkit in December 2023.
OQC	United Kingdom	Gate-based	Launched an "enterprise ready" quantum platform in November 2023 with an upgradeable 32-qubit system.
IQM	Finland	Gate-based	Launched a 20-qubit quantum computer in October 2023 and announced the development of a 50-qubit one on the way.
rigetti	USA	Gate-based	Announced its chip fourth generation (Ankaa-1) in August with a 4-qubit coupling method and a leap from 80 qubits to 84.
Google	USA	Gate-based	Claimed quantum supremacy in July 2023 of a random circuit sampling computation with 70-qubit Sycamore chip.
IBM	USA	Gate-based	Annouced a new high fidelity 133-qubit Heron chip in December 2023 aswell as the system two, a 3 linked Heron chip computer. Annouced a 1121-qubit chip demonstrator.
QILIMANJARO QUANTUM TECH	Spain	Annealing/Gate-based	Gave remote access to a 5-qubit gate based chip in July 2023. Aiming on the development of a 30-qubit chip.
D-Wave	Canada	Annealing	Demonstrated in April 2023 a coherent quantum spin glass dynamic on 5000-qubit from the 7000-qubit advantage2 chip launched in June 2022.
NEC	Japan	Annealing	Started joint research with Tohoku university using their 8-qubit quantum annealer.
ALICE & BOB	France	Gate-based	Announced Helium-1, a 16 bitflip corrected cat qubits computer in January 2024
FUJITSU	Japan	Gate-based	Annouced the launch of a 64-qubit system developped at Osaka University

Table 1 - 2023 update of superconducting qubits providers

With multiple different players representing different technology variants and computing paradigms, the superconducting market is mostly dominated by the USA big techs with the cold duel between **Google** and **IBM**. Google is following a clear strategy towards finding "quantum supremacy" since their first claim in 2019. Again, this year, Google's scientists published a paper claiming **quantum supremacy** obtained with performing a random circuit sampling task on an upgraded version of the **Sycamore chip** with **70-qubits**[40][41]. Even if the usefulness of such an algorithm is questionable, it has the advantage of demonstrating the continuous improvement of the technology and bringing the potential advantage of quantum computing over classical computing to the general public's attention. **IBM's** strategy, although also including the search for "quantum supremacy", seems to be more directed to **fault-tolerant quantum computing**, with the continuous increase of the qubit numbers over the years, and

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40 https://thequantuminsider.com/2023/07/04/google-claims-latest-quantum-experiment-would-take-decades-on-classical-computer/

41 https://doi.org/10.48550/arXiv.2304.11119

to the **reduction of noise error**. The announcement of the **1121-qubit Condor** system at the **IBM quantum summit** in December 2023 highlights IBM's desire to be one of the first companies to reach the 1000 qubit milestone. The announcement of the **133-qubit Heron chip** aiming to be a reliable **modular architecture with QPU interconnection** emphasizes the will of **IBM** to also target fault-tolerant quantum computing. IBM supports a roadmap targeting Large Scale Quantum interconnected computers by 2030 with **100 logical qubits**[42].

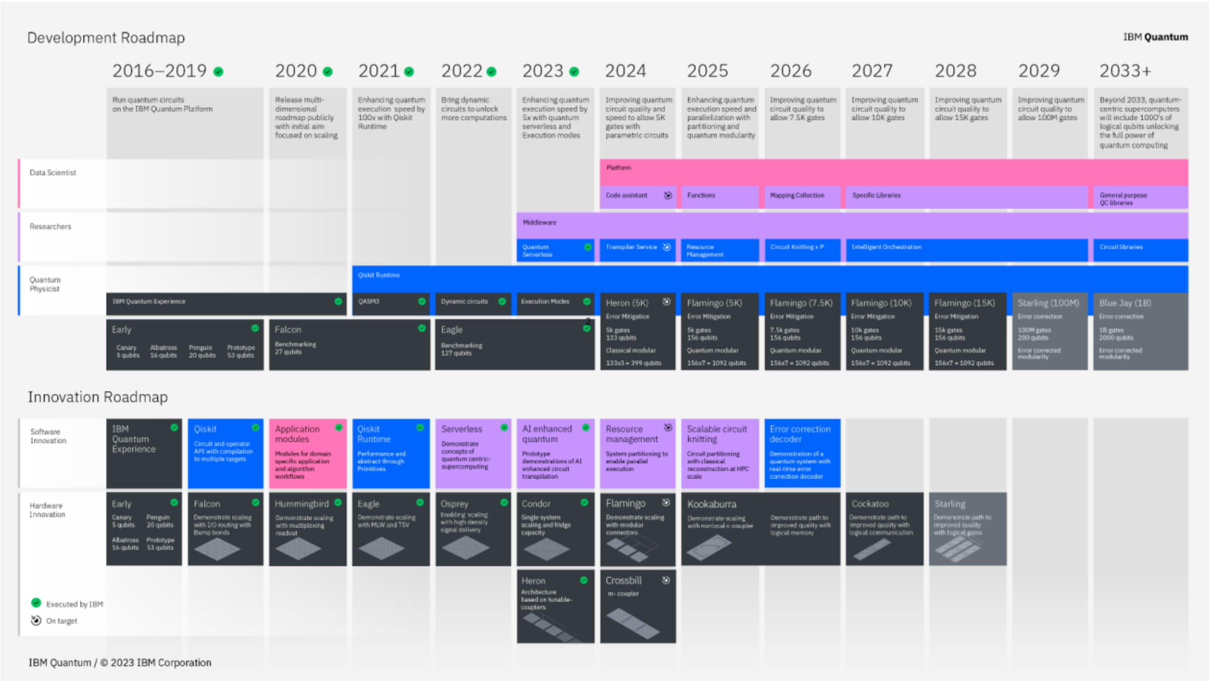

Figure 4 - IBM roadmap released in December 2023[43]

Among smaller players, there is also interesting news for 2023: the arrival in the market of European companies with smaller quantum computers.

Leading this small-scale quantum computer strategy is **Oxford Quantum Circuit** with their **32-qubit system** accessible via a cloud platform[44]. In Finland, **IQM** launched their **20-qubit system (deployed at VTT)**[45] and announced the development of **50-qubit** and **150-qubit systems**.

At a smaller scale, **Qilimanjaro** released a **5-qubit** remote access system and aims to develop and procure a **30-qubit** system to **Barcelona Supercomputing Center (BSC)**[46]. Later in 2023, **Fujitsu** and a consortium of academic partners announced the launch of a **64-qubit quantum platform**[47] developed at **Osaka University**. The access to the computer will be provided to Japanese users via the cloud.

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[42] https://www.hpcwire.com/2023/12/04/ibm-quantum-summit-two-new-qpus-upgraded-qiskit-10-year-roadmap-and-more/
[43] https://newsroom.ibm.com/2023-12-04-IBM-Debuts-Next-Generation-Quantum-Processor-IBM-Quantum-System-Two,-Extends-Roadmap-to-Advance-Era-of-Quantum-Utility
[44] https://quantumcomputingreport.com/oxford-quantum-circuits-receives-a-100-million-series-b-investment-and-announces-its-32-qubit-toshiko-platform/
[45] https://www.hpcwire.com/off-the-wire/iqm-and-vtt-unveil-finlands-2nd-quantum-computer-with-20-qubits/
[46] https://www.hpcwire.com/off-the-wire/qilimanjaro-advances-quantum-innovation-in-spain-with-qaas-delivery-to-bsc/, https://www.hpcwire.com/off-the-wire/iqm-quantum-computers-to-deliver-quantum-processing-units-for-1st-spanish-quantum-computer/
[47] https://www.hpcwire.com/off-the-wire/fujitsu-and-consortium-develop-advanced-64-qubit-quantum-computer-at-osaka-university/

In January 2024, the French company **Alice & Bob** announced their first system called **Helium 1**, carrying **16 bitflip-corrected superconducting cat qubits**[48]. They follow an approach focusing on the reduction of necessary qubits for fault tolerant computing using the property of cat qubits to be resistant to bitflip to a certain extent. Also in January, the US company **Rigetti** announced the public availability of their new chip **Ankaa-2**, increasing the 80 qubits of the previous generation to **84 qubits**. However, they also announced a big jump in performance by achieving a **median error rate** of **2%** on two-qubit gates, 2.5 times better than the previous generation[49]. In addition, the Canadian company **Anyon Systems** will set up **MonarQ**, a universal gate-based quantum computing device containing **24 superconducting qubits**, at Calcul Québec's data centre at École de Technologie Supérieure (ETS) in Montréal in January 2024[50].

ii. Photonic qubits

The area of photonic technologies, smaller in scale but with active start-ups development, offered a promising 2023 (see Table 2).

As first news, the announcement of the procurement of a **20-qubit photonic computer** developed by **ORCA Computing** at the **Poznan high performance computing center**[51] in Poland gives a good idea of the confidence placed in photonic technologies for industrial applications. By extension, the installation in November 2023 of a **2-qubit Quandela quantum computer** at **OVHCloud**[52], specifically designed to generate random numbers, should be mentioned.

In terms of recent development, the year began with a major leap in photonic technology when a team from **the University of Sussex** demonstrated accurate and **reliable qubit transfer between 2 QPUs** in February[53]. In October, **Chinese scientists** unveiled a **255-detected-photon** quantum computer[54] able to solve Gaussian Boson Sampling 10 quadrillion (10^{25}) times faster than the fastest classical computers. Finally, in France, the **EUROQCS-France** consortium was selected by the **EuroHPC Joint Undertaking** to host and operate a **photonic quantum computer**. The tender was launched in January 2024 for a delivery within 18 months[55].

In terms of funding, the market is growing with huge amounts being invested in various start-ups. Following **Xanadu** 's **$100-million** funding round in late 2022[56], **Quandela** raised **€50 million** in late 2022[57] to launch their **quantum computer factory** inaugurated **in Massy** in June 2023. Their goal now is to capture the North American market with an innovative, cutting-edge technology.

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48 https://www.hpcwire.com/off-the-wire/alice-bob-announces-tape-out-of-new-helium-1-16-qubit-quantum-processing-unit/
49 https://www.hpcwire.com/off-the-wire/rigetti-announces-public-availability-of-ankaa-2-system-with-a-2-5x-performance-improvement-compared-to-previous-qpus/
50 https://www.innovationnewsnetwork.com/monarq-quantum-computer-service-research/39474/
51 https://www.hpcwire.com/off-the-wire/poznan-supercomputing-and-networking-center-partners-with-orca-computing-for-quantum-photonic-systems-installation/
52 https://www.usine-digitale.fr/article/ovhcloud-achete-son-premier-ordinateur-quantique-a-quandela.N2111776
53 https://www.scientific-computing.com/news/researchers-advance-scalability-quantum-computers
54 https://english.news.cn/20231011/1dad728957b64b2189738e294391567f/c.html
55 https://eurohpc-ju.europa.eu/eurohpc-ju-launches-procurement-new-quantum-computer-france-2024-01-30_en
56 https://www.prnewswire.com/news-releases/xanadu-closes-100m-usd-series-c-to-accelerate-development-of-fault-tolerant-quantum-computers-301672611.html
57 https://www.lemonde.fr/economie/article/2023/11/07/ordinateur-quantique-la-start-up-francaise-quandela-leve-50-millions-d-euros_6198687_3234.html

company	country	computing technique	comments
XANADU	Canada	Analog simulation	Deployed a 216 squeezed-state qubits simulator on Xanadu cloud and Amazon braket in June 22.
ORCA Computing	United Kingdom	Analog Simulator	Will provide Poznan supercomputing center with a 20-qubit quantum boson sampling simulator
Ψ PsiQuantum	USA	Digital	Is aiming to deliver a first commercial quantum computing system by 2029 with a target of a million quantum bits.
QUANDELA	France	Digital	Delivered a 2 qubits quantum computer to OVH cloud in November 2023.
QuiX QUANTUM	Germany	Digital	Developed a 20 modes chip in 2022.
Q.ANT	Germany	Simulation	Developed a squeezed state of light demonstrator chip in June 2023.

Table 2 - 2023 update of photonic quantum computer providers

iii. Silicon-based qubits

Silicon qubits offer an advantage in terms of scalability and decoherence rate. However, it is still a fairly new field with only one major player working on the technology for 3 to 4 years (see Table 3). Most others emerged not eralier than two years ago and are still in a research phase. In 2023, only **Intel** announced the release of a **12 qubits chip**[58] that will be tested and characterized by different scientists from different laboratories. For the rest, most of the news comes from the various funding and announcement of the different goals of the start-ups in this area.

Other interesting news is the launch of the **C12 quantum fab** in Paris, a production centre for **carbon nanotubes qubits**[59].

58 https://www.hpcwire.com/2023/06/15/intel-debuts-tunnel-falls-quantum-chip-and-lqc-program-to-work-with-it/

59 https://www.usinenouvelle.com/editorial/la-start-up-c12-ouvre-une-fab-quantique-au-coeur-de-paris.N2199268

company	Country	computing technique	comments
QUANTUM MOTION	United Kingdom	Gate based	Raised £42 million in June 2023 to build a quantum microchip of 1024 quantum dots usable to build a scalable quantum computer
Silicon Quantum Computing	Australia	Gate based	Was aiming to demonstrate the capability of producing a reliable atomic scale integrated circuit by 2023 and to deliver a 100-qubit device embodying error correction by 2028.
equal 1	Ireland	Gate based	
photonic	Canada	Gate based	Raised $100M in November 2023 to build the first scalable fault-tolerant and unified quantum computer.
quobly	France	Gate based	Raised €19M in July 2023 to develop a fault-tolerant quantum processor
intel	USA	Gate Based	Realeased a 12 qubits silicon quantum chip in June 2023 and shipped it to different quantum scientists for research purposes.

Table 3 - 2023 update of spin qubit quantum computer providers

iv. Trapped ions

With the second biggest number of players in the quantum computing ecosystem (see Table 4), **trapped-ion qubits** are a fast growing technology. Without any "big tech" directly involved in the development of the technology, the field is left with high competition and no clear dominance of any particular vendor.

In May 2023, probably the most important news came from **Quantinuum** with the announcement of the creation of **controllable non-abelian topological quantum matter**[60], opening the path to topological quantum computers. In the competition, using their algorithmic qubit metric, **IonQ** announced a **29- and a 35-algorithmic-qubit quantum computer**. They additionally demonstrated a **99.9% fidelity 2-qubit gate**, promising news as it defines the accuracy threshold for the application of error correction algorithms[61].

In Europe, **AQT** signed in December 2023 a contract to install a **20-Qubit quantum computer** at the **LRZ supercomputing center in Munich**[62]. In October 2023, the consortium **EuroQCS-Poland** selected by **EuroHPC JU** launched a tender for the procurement of a **trapped ion quantum computer** targeting European technologies[63].

More recently, the Japanese research institute **RIKEN** announced its collaboration with the American trapped-ion company **Quantinuum** to install and couple their **20-qubit system H1**. This marks the launch of RIKEN's quantum Quantum-HPC hybrid platform announced earlier in April 2023[64].

[60] https://www.hpcwire.com/2023/05/09/quantinuum-launches-h2-reports-breakthrough-in-work-on-topological-qubits/
[61] https://insidehpc.com/2023/10/quantum-ionq-announces-29-algorithmic-qubits-on-barium-platform/
[62] https://www.quantum.lrz.de/bits-of-qubits/detail/a-trapped-ion-quantum-computer-for-the-munich-quantum-valley
[63] https://eurohpc-ju.europa.eu/eurohpc-ju-launches-procurement-euroqcs-poland-2023-10-16_en
[64] https://insidehpc.com/2024/01/riken-selects-quantinuum-for-hybrid-quantum-hpc-platform/

company	Country	computing technique	comments
QUANTINUUM	USA	Gate-Based	Launched in May 2023 the H2 system, a 32-qubit system on which they claim to have created and controled non-abelian topological quantum matter.
IONQ	USA	Gate-Based	Made available a 29 algorithmic qubits system (IonQ Forte) on amazon braket. Announced IonQ Forte Entreprise with expected 35 algorithmic qubits.
QUANTUM FACTORY	Germany	Gate-Based	Planned to design and build a universal Ion-based quantum computer by 2023 but no tangible news supporting the plan.
AQT	Austria	Gate-Based	Signed a contract in December 2023 to install a 20-qubit quantum computer in the supercomputing center LRZ.
oxford ionics	United Kingdom	NA	Raised £30 millions in January 2023 to "end the quantum computing race". No information found about their technology.
eleQtron	Germany	NA	Recieved 9.1 million euro funding from German government in 2022 to develop their quantum chip concept (MAGIC).
CRYSTAL QUANTUM COMPUTING	France	Gate-Based	Aim to commercialize a trapped ion quantum computer by 2026.

Table 4 - 2023 update of trapped ions quantum computer providers

v. Neutral atoms

A smaller number of players are active in neutral atom qubit technologies compared to superconducting and trapped ion qubit technologies (see Table 5). However, neutral atom technology had a fruitful 2023. With what appears to be a slowdown in **ColdQuanta**'s neutral-atom computing activities following its acquisition by **Infleqtion**, the market is now dominated by just three vendors: **Pasqal**, **Atom Computing** and **QuEra**.

After the development of a **324-qubit computer** by **Pasqal**[65] and a **256-qubit computer** by **QuEra** in 2022[66] the race was on for the development of a **1,000-qubit computer**, an important milestone on the road to fault-tolerant quantum computing. The race seems to have been won by **Atom Computing** with the announcement of the first ever fully programmable **1,000-qubit quantum computer**[67] in November 2023. However, this information should be tempered because **no scientific article** or technical information on the computer has been published.

On the algorithmic side of the road of fault-tolerant quantum computing, **QuEra** partnering with MIT and the University of Maryland, demonstrated a **48-qubit error corrected algorithm** using their technology[68]. The recent QuEra roadmap is shown in Figure 5.

In Europe, **Pasqal** focused more on the software development part of programmable neutral atom computers with the release of **Qadence**[69], a quantum programming library for **Analog-Digital quantum computing**. Moreover, **Pasqal** is also working on the deployment of **two 100+-qubit systems** in the French **TGCC supercomputing center** and the German **Jülich Supercomputing Centre (JSC)** in the

[65] https://thequantuminsider.com/2022/11/21/review-of-pasqals-quantum-computing-technology-in-2022/
[66] https://www.quera.com/aquila
[67] https://www.hpcwire.com/2023/10/24/atom-computing-wins-the-race-to-1000-qubits/
[68] https://doi.org/10.1038/s41586-023-06927-3
[69] https://www.pasqal.com/articles/pasqal-unveils-qadence-a-quantum-programming-library-for-digital-analog-quantum-computing

context of the EuroHPC JU project **HPCQS**. They also launched a **$90-million** initiative with **Investissement Quebec**, to deploy a **quantum computing factory** in Sherbrooke (Canada)[70].

The market for neutral atoms is also growing significantly with recent funding. With **€100 million** raised, **Pasqal** even became the most funded European start-up in quantum computing[71].

company	country	computing technique	comments
PASQAL	France	analog simulator	Raised 100 millions euro to develop a 1000-qubit computer.
atom computing	USA	Gate-based/Analog simulation	Announced a 1000-qubit quantuml computer in November 2023.
ColdQuanta	USA	sensing	After the takeover of Infleqtion, the focus has been put more on sensing than quantum computing.
QuEra Computing Inc.	USA	analog simulator	Launched a 256-qubit analog computer in november 2022. Announced working on a 10000-qubit digital computer.

Table 5 - 2023 update of neutral atoms quantum computer providers

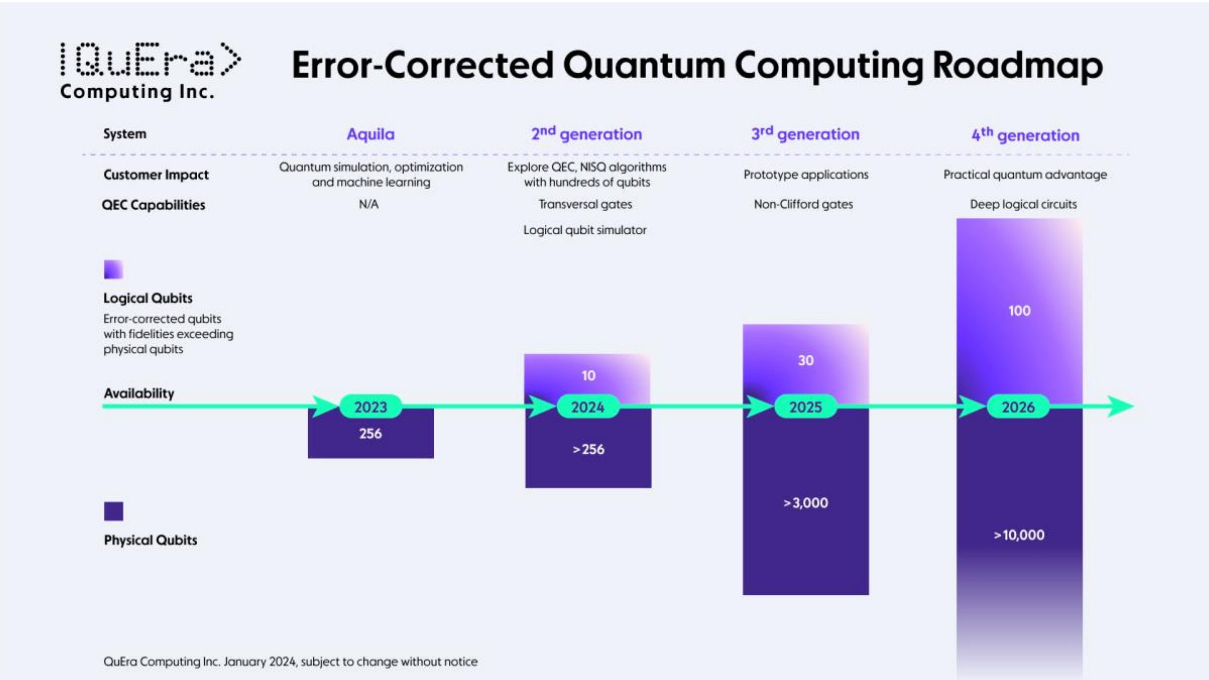

Figure 5 - QuEra roadmap released in January 2024[72]

vi. Other technologies

Among the variety of qubit technologies, NV-center diamond qubits are worth mentioning. The aim of this technology is to develop room-temperature qubits using NV centers in diamond. Suppliers of NV-

[70] https://www.hpcwire.com/off-the-wire/pasqal-and-investissement-quebec-launch-90m-quantum-computing-initiative/
[71] https://www.hpcwire.com/off-the-wire/pasqal-raises-e100m-series-b-funding-to-advance-neutral-atoms-quantum-computing/
[72] https://www.quera.com/events/queras-quantum-roadmap

center quantum computers include **Quantum Brilliance, SaxonQ**, **XeedQ** and research teams from academia.

In November 2023, a publication by the **University of Chicago**, **Argonne National Laboratory** and **Cambridge University** showed the possibility of **low-equipment, low-expense operating qubits** using the process of **diamond dilation**[73]. It follows the announcement in April from **Pawsey Supercomputing** center and **Quantum Brilliance** of running a **room-temperature quantum algorithm**, an important milestone in the demonstration of the usability of room-temperature NV-center diamond qubits.

Another approach, followed by **Microsoft** and still debated in the community is the development of **topological qubits**, employing **anyons quasi-particles braids**. This technology is supposed to bring a **very stable and robust result** compared to other approaches. However, the feasibility is still to be demonstrated. Nevertheless, in 2023, **Microsoft** was chosen by the **Defense Advanced Research Project Agency (DARPA)** with two others industrials for the **Unexplored Systems for Utility-Scale Quantum Computing (US2QC)**[74]. The aim of the project is to determine the possible utility of underexplored quantum approaches such as topological qubits.

b. Middleware & HPC integration

In the field of HPC and quantum computing integration, several contracts have been signed in 2023 between technology providers and HPC centers for the installation of QPU units coupled to HPC hardware. The case of **AQT** signing a contract for the installation of a **20-qubit chip** at the **LRZ center in Munich** has already been discussed, as well as the case of **ORCA Computing** signing a contract with **Poznan Supercomputing center** for the installation of two of their **PT-1 systems**.

Moreover, in Europe, the **EuroHPC Joint Undertaking** launched a **€10M tender** in November 2023 to create **excellence centers in quantum computing** focusing on fostering the integration of quantum systems in HPC centers focusing on the development of industry ready HPC-quantum use-cases[75].

In the USA, **NVIDIA** announced **SEEQC**, an **all-digital, low-latency link between quantum computers** and NVIDIA's Grace Hopper GPU platform[76]. This link is announced to be compatible with any quantum computing system aiming to answer the ever-increasing demand of computing power for AI model training. The platform is to that end supporting practical implementations of quantum machine learning algorithms as well as diverse data-center scale applications. Finally, the approach is presented as scalable using low-latency interconnections and allowing modularity with different quantum architectures.

c. Quantum computing offers of cloud providers

Three years after the launch of **Amazon bracket**, 2023 marks the involvement of new major cloud providers in the world of quantum computing. Starting in August with the launch by **China mobile** of China's largest **cloud quantum computing platform**. The platform has been developed in collaboration with **China electronic group corps**, a company developing a **20-qubit chip** (technology not found). The

[73] https://news.uchicago.edu/story/researchers-invent-new-way-stretch-diamond-better-quantum-bits
[74] https://thequantuminsider.com/2023/12/30/darpa-excited-about-microsoft-psiquantum-approaches-to-utility-scale-quantum-computing/
[75] https://eurohpc-ju.europa.eu/european-quantum-excellence-centres-qecs-applications-science-and-industry_en
[76] https://quantumcomputingreport.com/seeqc-integrates-nvidias-grace-hopper-cpu-gpu-into-its-control-stack/

aim of this platform is to give both industrial players and university researchers access to state-of-the-art quantum technology to see the rise of industrial applications of quantum computing[77].

In France, the cloud provider **OVHcloud** announced the procurement of a **2-qubits photonic chip** developed by **Quandela** in a modular architecture, allowing for future extension. The aim of this acquisition is the development of a pure random number generation procedure to safer network key generations. Moreover, the access will be given to **OVH**'s research and development teams to experiment diverse use cases based on photonic QPUs. **Quandela** also partnered with **Scaleway** to provide on-demand quantum computing services. The aim would be to provide an efficient GPU accelerated quantum emulator based on NVIDIA H100 GPUs as well as a cloud access to Quandela's services and QPUs[78].

In November 2023, the American cloud provider **Equinix** announced the launch of a partnership with the French company **Alice & Bob** to provide secure access to **Equinix**'s clients to the **1-qubit QPU**[79].

d. Software environments and algorithms

Quantum computers at their current form need to be combined with classical computers. This is a challenge because the development of quantum technologies is more in experimental physics than in computer science. But even though it is challenging, most developers of the technology came up with their own software development environment, and many third-party companies are now trying to find their way in the ocean of quantum software. Here, two strategies can be easily distinguished that reflect two different philosophies of quantum computing. The first tends towards a "hardware agnostic" tropism where the technology used doesn't change the way the software is used. Among them, the uncontested leader **Qiskit** with its **1.0 version,** announced at the **IBM** quantum summit week in December 2023, promised better performances and the ability to control **1000+ qubits systems,** which is likely to be the size of future machines.

Eviden, which also takes a hardware agnostic approach, is focusing more on high performance integration with the launch of **Q-Pragma**. It is a **C++ directive-based language** aimed at HPC integration of QPU[80]. The language is presented as scalable and capable of running on error-corrected hardware, making it a good candidate for future middleware in HPC integration. On a similar note, **NVIDIA** is developing **CUDA Quantum**[81] with similar goals, but with an approach closer to systems that allow gate-based and pulsed programming. In collaboration with Quantum Machines, a new system for accelerated quantum-classical computing has been announced, offering a low latency hybrid architecture interconnecting NVIDIA GPUs with QPUs.

CUDA Quantum is becoming de facto a concurrent to **EVIDEN's Qaptiva™** solution. On a smaller scale, **Fraunhofer FOKUS** published in May 2023 a high-level Open-Source programming framework which is also following this philosophy, but aiming for gate-based coding[82].

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77 https://www.globaltimes.cn/page/202308/1296632.shtml
78 https://www.scaleway.com/fr/news/quantum-as-a-service-qaas-quandela-et-scaleway-sunissent-pour-democratiser-linformatique-quantique/
79 https://thequantuminsider.com/2023/11/17/collaboration-to-offer-equinix-customers-secure-access-to-alice-bob-quantum-tech/
80 https://thequantuminsider.com/2023/11/15/eviden-makes-progress-in-enhancing-the-scalability-of-qubit-emulation-and-platform-capabilities/

81 https://developer.nvidia.com/cuda-quantum
82 https://www.fokus.fraunhofer.de/en/fokus/news/qrisp-framework-available_2023_05

The other strategy, the "Hardware specific" one, which is mostly carried out by the technology developers, also saw some major improvement, especially in the field of neutral atoms. **PASQAL** announced one of the first digital-analog quantum computing libraries called **Qadence**. With this, they hope to fill the gap left between a pure analog neutral atom control library such as Pulser and the other usually gate based one by allowing a hybrid way of coding on neutral atom systems.

e. Use cases – announcements of new industrial partnerships

i. Quantum random number generation (QRNG)

With the installation of small-scale photonic devices in various cloud providers and HPC centers, it is natural to start developing QRNG protocols.

In June 2023, a Chinese team from the **University of Nanjing** developed a new **protocol for generating random numbers** based on detection of single photons[83]. This protocol would theoretically secure quantum information tasks.
At the end of the year, the company **Quantum Dice** released a QRNG product that would be launched in the **SpeQtral-1** satellite. Combined with a **Quantum Key Distribution (QKD)** device, the satellite would provide secure quantum communications[84].

ii. Quantum Chemistry

The year 2023 was rich in collaborations and discoveries in the field of quantum chemistry. In July, **Quantinuum** announced the **simulation of an H2 molecule** using an **error-corrected quantum computer** paving the way for fault-tolerant quantum chemistry simulations[85]. QPU vendor **Pasqal** partnered with **Qubit Pharmaceutical** in September to develop a **model-based drug discovery algorithm**. The goal would be to have quantum superiority in that field by 2025 by running the algorithm on Pasqal's neutral atom QPUs[86].

The year also ended with a **Qubit Pharmaceuticals** breakthrough carried out with **Sorbonne University** and **simulating a 40-qubit system**. This was done using the French **HPC supercomputer Jean Zay[87]**. This demonstration will be of great interest for the development of new quantum algorithms and gives Qubit Pharmaceuticals a good head start to become one of the world's leading companies in modeling-based drug discovery.

On a more industrial level, **Rolls-Royce** announced a partnership with **Riverlane** and **NQCC** for the acceleration of new materials discoveries. The aim of this partnership is to build computational tools to **simulate large, complex materials** on quantum computers and prepare aeronautical players for the arrival of quantum computers for simulations[88].

In the automotive industry, quantum chemistry seems to also be a hot topic. In particular, **BMW** and **Ford** have been investigating the simulation of **Li-ion battery and fuel cells** using quantum

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[83] https://scitechdaily.com/taking-quantum-security-to-new-heights-a-new-secure-and-fast-source-di-qrng-protocol/
[84] https://www.quantum-dice.com/quantum-dice-and-speqtral-unveil-quantum-communication-developments-with-zenith-qrng-for-speqtral-1-mission/
[85] https://www.hpcwire.com/off-the-wire/quantinuum-leverages-logical-qubits-for-1st-successful-quantum-simulation-of-a-chemical-molecule/
[86] https://www.hpcwire.com/off-the-wire/pasqal-and-qubit-pharmaceuticals-join-with-unitary-fund-to-win-wellcome-trusts-quantum-for-bio-program/
[87] https://thequantuminsider.com/2023/12/06/qubit-pharmaceuticals-sorbonne-university-simulate-quantum-calculations-of-more-than-40-qubits-on-conventional-computers/
[88] https://www.nqcc.ac.uk/updates/nqcc-rolls-royce-and-riverlane-partner-to-accelerate-materials-discovery/

computers[89]. **BMW**, with **Airbus** and **Quantinuum** also announced a collaboration aiming to **optimize fuel cell reaction** using quantum computing with a direct application in new batteries development[90]. Moreover, **Quantinuum** demonstrated the first successful **quantum simulation of a chemical molecule using logical qubits**, paving the way for fault tolerant quantum chemistry simulations.

iii. Logistic and optimization

Optimization can be seen as one of the most promising topics for demonstrating NISQ supremacy.

The year began with the demonstration of a quantum advantage in optimization problems with a **5,000-qubit programmable spin glass** by **D-Wave** scientists[91]. **HSBC** partnered with **Terra Quantum** to develop a quantum optimization method applied to the **efficient allocation and management of collateral assets[92]**.

In July, **Multiverse Computing** announced a collaboration with Iberdrola for the development of quantum solutions for **smart-grid optimization[93]**. In September, **NEC** launched a management and **business optimization consulting service**, aiming to develop company partnership and advocate the development of quantum algorithms for industrials[94].

In December, the German company **SAP** announced the integration of **quantum algorithms services for vehicle space optimization[95]**. Partnering with **IBM** for the access and usage of their quantum computing platform, a **QAOA-based optimize**r has been developed as a proof of concept for a real-world usage of quantum algorithms.

AIRBUS, partnering with **IBM**, is working on the application of **quantum chemistry simulations** using quantum computing to **develop new materials resistant to corrosion** by computing the energy involved in the water reduction reaction.

iv. Finance and Insurance

Financial applications of quantum computing have been widely researched during the year. Starting with a joint experiment between the French bank **Crédit Agricole** in a partnership with **Multiverse Computing** and the neutral atom QPU provider **Pasqal**, two real use-case experiments have been run using quantum inspired algorithms, **showing runtime acceleration as well as memory optimization**. This is paving the way for a new classical computing paradigm inspired by quantum applications[96].

This was followed later in the year by the joint publication by researchers from **New York University** and **Toronto University** of a paper demonstrating the potential use of quantum computing for the **prediction of a cascading financial crisis[97]**.

89 https://www.smart-energy.com/regional-news/north-america/ford-and-bmw-investigate-quantum-computing-to-improve-ev-mobility/
90 https://www.airbus.com/en/newsroom/press-releases/2023-08-bmw-group-airbus-and-quantinuum-collaborate-to-fast-track
91 ttps://doi.org/10.1038/s41586-023-05867-2
92 https://terraquantum.swiss/news/hsbc-and-terra-quantum-explore-real-world-applications-of-hybrid-quantum-technologies-in-financial-services
93 https://www.hpcwire.com/off-the-wire/multiverse-computing-and-iberdrola-collaborate-on-quantum-solutions-for-future-ready-smart-grids/
94 https://www.nec.com/en/press/202309/global_20230913_01.html
95 https://news.sap.com/2023/12/vehicle-space-quantum-poc-enterprise-applications/
96 https://pressroom.credit-agricole.com/news/quantum-computing-two-real-world-experiments-conducted-by-credit-agricole-cib-in-partnership-with-pasqal-and-multiverse-computing-produce-conclusive-results-in-finance-cddc-94727.html
97 https://thequantuminsider.com/2023/03/11/timely-research-quantum-computers-could-help-reduce-cascading-financial-crashes/

In January 2024, **Rigetti** announced a partnership with **Moody's analytics**, a global financial intelligence and analytic leader[98]. This partnership focuses on achieving quantum supremacy for a real-world use case targeting financial applications such as **recession forecasting using quantum-enhanced data transformations**.

Also in January 2024, **Rigetti** has been awarded an **innovative UK grant** with the aim to develop **quantum machine learning techniques for financial data streams**[99].

v. Computational Fluid Dynamic (CFD)

In May 2023, **Classiq, NVIDIA** and **Rolls-Royce** announced a breakthrough for **fluid dynamic simulation in jet engines**. Using NVIDIA's Grace Hopper platform, a research team managed to emulate the largest quantum circuit for CFD **with 39 qubitsl**[100].

Also in May 2023, the French companies **Eviden**, **ColibrITD** and the research center **ONERA** announced a partnership around what has been called the **VulQain project**. It aims to develop the first hybrid platform capable of **addressing complete combustion phenomenon simulation**, tackling their extreme complexity[101].

vi. Artificial Intelligence

In Canada, **Pasqal** announced a Partnership with **MILA**, a research institute in artificial intelligence, with the aim to explore the possibility of **quantum computing in enhancing generative models**. The research project, running over a year, will explore the interaction between the two fields that has yet not really been addressed[102].

vii. Life Science

The Israeli Quantum Software company **Classiq** announced a collaboration with **NVIDIA** and the **Tel-Aviv Sourasky Medical Center**. This collaboration is oriented on the development and **application of Classiq's software to life science and healthcare**. This development will be done with the help of NVIDIA's H100 tensor core GPUs platform to emulate efficiently the different algorithms and maybe make use of quantum inspired algorithms to accelerate already existing healthcare and life science algorithms[103].

viii. Earth Observation

In Germany, **Forschungszentrum Jülich** was leading a new joint project with a wide multi-disciplinary consortium including **ESA**, **the institute for quantum computing analytics**, **Thales**, **the national institute for nuclear physics** and **IQM**. Called **QC4EO**, it targets the possibility of quantum advantage

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98 https://thequantuminsider.com/2024/01/04/rigetti-computing-moodys-analytics-deepens-collaboration-sets-ambitious-research-agenda/
99 https://thequantuminsider.com/2024/01/15/rigetti-computing-awarded-innovate-uk-grant-to-develop-quantum-machine-learning-techniques-for-financial-data-streams/
100 https://nvidianews.nvidia.com/news/nvidia-rolls-royce-and-classiq-announce-quantum-computing-breakthrough-for-computational-fluid-dynamics-in-jet-engines
101 https://www.onera.fr/fr/actualites/eviden-colibritd-and-onera-unissent-leurs-forces-pour-construire-la-premiere-plateforme
102 https://mila.quebec/pasqal_mila/
103 https://www.classiq.io/insights/classiq-announces-quantum-center-for-life-sciences-in-collaboration-with-nvidia

for **earth observation algorithms**. Launched in March 2023, this project was aiming for more long-term applications running between 3-5 years to 15 years from now[104].

3 Results

The data exposed in this report are coming both from **direct discussions and conferences**, and from **public information available online**. Confidentiality of information is key in our respective relationships with the quantum computing industry, so no sensitive or confidential data was included in the document.

This monitoring of the various fields related to the quantum computing industry in all geographical regions has supported HPCQS members' reflections on the development of quantum computing technologies. It also assisted them in adjusting the focus of their efforts to support their user communities.

A key take-away of this technology watch is that the **collection and analysis of data must necessarily be shared among several partners**. The aim is to **process information and opinions on a regular basis** to ensure that they are subsequently shared with other partners. Having a shared dynamic collaboration environment would foster the participation of many partners.

At a time when numerous updates are published on the technical progress of quantum computing, it is also important to **check the facts** proclaimed by the various players. Individuals such as Olivier Ezratty in France, and Scott Aaronson in the US play a pivotal role in **deciphering communications** and trying to **mitigate the hype**.

4 Conclusions

Collecting all of this data through 2023 allowed us to realize a new shift in the discussions related to quantum computing technologies: **error correction schemes and increased scalability have become a reality**. Like John Preskill commented in his keynote at the Q2B Conference in Santa Clara (CA) in December 2023: "as best as we currently understand**, the path to quantum value is along the road to a fault-tolerant quantum computing**, and that has daunting implications for our field and for the quantum industry". NISQ platforms are there to support research in this field and to help our communities get acquainted with these new paradigms and systems. But when it comes to getting real actionable value, we'll need to reach higher levels of scalability and accuracy.

Amongst the technologies that are beginning to appear as key opportunities to reach the level of scalability required to perform error correction, **quantum interconnects and quantum memories** should definitely bring some food for thoughts in the coming months. Also, **efforts to produce higher fidelity qubits like cat qubits** promoted by Alice & Bob in France and AWS in the US, should be widely influential. IBM, amongst other players, has bet on both segments: improving the level of quality of its qubits, and at the same time, trying to connect several QPUs through various interconnection technologies (classical, and then quantum).

Public infrastructures are emerging, which aim at coupling HPC and quantum. We should see **increasing results from these first integrated platforms**, either from Japan (RIKEN) or Europe (the seven EuroHPC Hosting Entities for HPC-QC) in the coming months. This will definitely appear in the next edition of this technological watch report (D2.4).

[104] https://www.hpcwire.com/off-the-wire/julich-leads-qc4eo-new-joint-project-studying-quantum-advantage-for-earth-observation-applications/