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THIS IDC MARKETSCAPE EXCERPT FEATURES IBM

IDC MARKETSCAPE FIGURE

FIGURE 1


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IN THIS EXCERPT

The content for this excerpt was taken directly from IDC MarketScape: Worldwide Quantum Computing Systems 2023 Vendor Assessment (Doc # US49607923). All or parts of the following sections are included in this excerpt: IDC Opinion, IDC MarketScape Vendor Inclusion Criteria, Essential Guidance, Vendor Summary Profile, Appendix and Learn More. Also included is Figure 1.

IDC OPINION

IDC projects that worldwide spend on quantum computing technology (including hardware, software, and as-a-service solutions) will grow from $1.1 billion in in 2022 to $7.6 billion in 2027, a five-year CAGR (2022-2027) of 48.1% (see Worldwide Quantum Computing Forecast, 2023-2027: Surfing the Next Wave of Quantum Innovation, IDC #US49198322, August 2023). Driving this spend is the expectation that quantum computing will deliver the compute power needed to revolutionize organizations' ability to solve some of today's most complex scientific problems. For example, by using this technology, engineers will be able to simulate the natural processes that will result in new materials needed to design safer and more energy-efficient batteries, automobiles, electronics, and so forth. Scientists will be able to develop personalized medicines capable of treating incurable diseases, as well as find possible solutions to combat climate change. Companies in all industries will be able to leverage quantum computing to identify the most optimal solution for a problem with many solutions. Other organizations and enterprises will be able to solve complex algebraic problems that could lead to advances in quantum machine learning (ML) and AI. However, today's quantum computing technology is far from commercial maturity. The ability to solve these, and other intractable problems, requires a high number of quality qubits, which can be scaled while still performing with high fidelity. Owing to the instability of today's qubit technology, today's noisy intermediate-scale quantum (NISQ) systems are only suitable for small-scale experimentation.

Yet the quantum era is approaching quickly due to the vast amount of money being invested into the development and advancement of quantum computing by public and privately funded institutions, government spending worldwide, internal allocations (research and development [R&D] spend) from technology and service vendors, and external funding from venture capitalists and private equity firms. IDC expects that worldwide investments in the quantum computing market will grow to $16.4 billion by the end of 2027. Already, these investments have led to waves of technological innovation and breakthroughs, which have allowed for the development of quantum systems that can be used by enterprises for small-scale experimentation, identification of use cases, and learning how to program quantum algorithms. Recent announcements regarding advancements in quantum hardware and software, as well as error mitigation and suppression, provide speculation that quantum systems capable of delivering a near-term, though still smaller-scale, quantum advantage may be realized in the next five years. Eventually, the continued investment into quantum computing is expected to result in the realization of the fault-tolerant quantum machine that is capable of addressing the ever-growing list of complex use cases. When this will occur and for which quantum modality are still uncertain.

Yet quantum hardware vendors realize that as these advances are made, quantum computing must be accessible and usable to end users who want to start experimenting with the technology now. Within the past year, previously inaccessible quantum modalities of quantum computing became accessible for end-user experimentation. Other quantum hardware vendors announced partnerships for on-
premises quantum deployments. Quantum software vendors began launching frictionless software offerings for nonquantum specialists. In addition, quantum hardware and software vendors announced the anticipated launch of new scientific accelerator platforms, which will help with the integration of quantum, AI, and HPC. All of these offerings are made available through quantum computing infrastructure-as-a-service (QCIaaS), quantum computing platform-as-a-service (QCPaaS), and quantum computing software-as-a-service (QCSaaS) offerings from quantum hardware, cloud service providers, and software vendors, respectively, as a means to provide end users the tools and resources needed to experiment with quantum computing systems.

Given the current state of quantum development, IDC continues to hold the position that the so-called "race to a fault-tolerant quantum computer" will not result in one winner, but several winners that will provide a unique solution for solving specific types of problems for specific industries. In the long term, the evolution of quantum computing over time will enable more enterprises to solve more complex problems. In the short term, enterprises should consider experimenting with a variety of quantum computing technologies to determine which vendor and modality best fits their quantum needs.

IDC MARKETSCAPE VENDOR INCLUSION CRITERIA

This IDC MarketScape is an evaluation of quantum computing vendors worldwide. Quantum computing is a nascent market comprised of several established IT and start-up companies working to develop a quantum computing system. However, many of these companies are still in the developmental stages of their quantum research and development and thus have either not released a quantum computing system, which can be accessed and used by enterprises and organizations for quantum experimentation, or have only provided open source access to their quantum systems specifically so that quantum developers can experiment with the technology to advance quantum computing research. In addition, while all quantum hardware developers are basing their technology on the quantum properties of qubits, not all quantum hardware developers are leveraging or exploiting the quantum properties of qubits in the same way. To ensure consistency between the types of quantum hardware vendors and technologies being assessed in this study, this IDC MarketScape focuses on quantum computing hardware developers that have advanced to the vendor stage and are able to provide a premium service to enterprises and organizations interested in identifying quantum use cases, developing quantum algorithms, and so forth using circuit (gate-based) quantum computing systems. These premium services can include cloud or on-premises access to circuit (gate-based) quantum computing hardware, software, and other tools needed for quantum experimentation, as well as access to quantum professional services that can assist with the quantum journey. IDC used the following inclusion criteria for quantum hardware vendors included in this IDC MarketScape:

- The quantum hardware vendor must have developed and was providing access to its quantum computing systems for a premium fee either through on-premises deployment or via the vendor's QCIaaS offering, or a cloud service provider's QCPaaS offering as of January 1, 2022.
- The vendor's primary core quantum computing system must be available for use as a premium service for enterprises to experiment with quantum computing use cases and applications.
- The vendor must have been the primary developer of a circuit (gate-based) quantum computing system, which is accessible via the company's premium plan.

IDC opted to exclude cloud service providers that provide access to quantum computing systems developed by other quantum hardware vendors, but do not develop and offer access to their own
quantum computing systems since this evaluation focused on quantum hardware vendors specifically. IDC opted to exclude quantum hardware vendors that were developing noncircuit (gate-based) systems to ensure that the same types of technology were being compared, as were the uses for that technology.

IDC made every effort to include all quantum hardware vendors that met the inclusion criteria through responses provided by the vendor in a web-based eligibility survey, in-person or virtual discussions, as well as publicly available information. Further, all quantum hardware vendors included in this study had the opportunity to provide detailed information about their premium service through in-depth interviews, web-based surveys, and customer feedback inquiries (i.e., interviews and survey). The quantum hardware vendors included in this study also were given an additional opportunity to review their scores and profiles for factual accuracy prior to the publication of this document.

**ADVICE FOR TECHNOLOGY BUYERS**

Despite quantum computing still being in the early stages of development, this technology is expected to be an industry disruptor, resulting in a competitive advantage across multiple industries, but only for those enterprises that are quantum ready. Though, today's quantum hardware vendors are challenged in delivering systems that scale to the large number of qubits needed to achieve a near- or long-term advantage due to the fragility of the qubits that are the building blocks of quantum systems, enterprises should not be deterred or delayed in the commencement of their quantum journey. The following are some steps that enterprises should consider before and during their quantum journey:

- **Appoint a quantum champion and quantum research team:** Enterprises interested in quantum computing, but unsure where to start, should consider appointing a quantum computing champion and quantum computing research team to guide the journey. This dedicated group of individuals would have the key responsibility of becoming quantum aware through training and other educational opportunities. Using this knowledge, not only will the quantum champion and research group be able to educate others within the organization, they also will be able to use their quantum knowledge to help determine whether the organizational goals and priorities can be best met by using quantum computing to solve their most complex problems.

- **Become an active participant in the quantum ecosystem:** The quantum champion and quantum research team start forming relationships with industry partners and others that are already part of the quantum ecosystem. As active members of the quantum ecosystem, the quantum champion and research group can begin to gain insights from industry partners regarding quantum adoption and implementation, challenges, and other valuable information that can better inform the enterprise at all stages of their quantum journey.

- **Let quantum computing road maps pave the way:** When considering a quantum computing hardware vendor, enterprises should evaluate the quantum computing developmental road maps from multiple quantum hardware vendors. Quantum computing road maps should be viewed by enterprises as tools that can be used to guide their quantum computing initiatives. The more detailed information that is included in a quantum computing developmental road map, the more confident enterprises can be that the quantum hardware vendor can meet their current and future quantum computing needs. Further, quantum computing development road maps can help reduce the hesitancy of quantum adoption among technology buyers that view quantum computing investments as a gamble due to the lack of available skill sets and uncertainty as to when and how quantum advantage will be realized.
- **Establish a valued partnership**: A valued partnership with a quantum hardware vendor can be key to a successful quantum journey. While quantum hardware vendors provide access to quantum technology, they also can provide valuable knowledge about which organizational use cases are best suited for running on quantum and how to program algorithms to gain the most optimized results and provide a marriage between quantum and domain knowledge that will help align quantum hardware with the right use case.

- **Experiment with a variety of potential use cases with a variety of quantum computing technologies**: With quantum computing still in the early stages of development, there are still many unknowns about the technology. For example, will certain quantum computing modalities be better suited for solving certain problems? When will quantum advantage first be realized, by which type of quantum modality, and for what use case. With so many unknowns, it is important for enterprises to be as prepared as possible. Experimenting with several use cases will allow enterprises an opportunity to assess how quantum can be best leveraged to gain value in both the near term and the long term. Experimenting with different types of quantum modalities will enable enterprises to compare the performance of multiple systems to determine which best suited their quantum needs.

- **Begin thinking about quantum computing as a continuum of the performance-intensive environment**: Quantum computing is not a standalone technology. Instead, quantum computing will function as part of a hybrid quantum computing environment where it can be leveraged to augment the results gained from performance-intensive computing such as HPC and AI. This will occur either by solving portions of performance-intensive workloads that are beyond the scope of classical compute technology, accelerating the computations, reiterating results generated on classical compute systems, and so forth. However, integrating quantum computing into the performance-intensive environment will take planning and time. Enterprises should start preparing for this now.

Despite the complexities related to quantum computing development, the quantum era is approaching faster than some might expect. While still far from being commercially ready, advancements in the development of quantum computing hardware are continuously being announced by quantum hardware vendors. Enterprises seeking to use quantum computing to gain a competitive advantage need to be experimenting today to be quantum ready tomorrow.

**VENDOR SUMMARY PROFILES**

This section briefly explains IDC’s key observations resulting in a vendor’s position in the IDC MarketScape. While every vendor is evaluated against each of the criteria outlined in the Appendix, the description here provides a summary of each vendor’s strengths and challenges.

**IBM**

IDC has positioned IBM in the Leaders category in this 2023 worldwide IDC MarketScape on quantum computing systems.

As a pioneer in quantum computing space, IBM commenced its quantum computing journey in February 1970, when Charles H. Bennet coined the term *quantum information* in the publication *Quantum Information Science*. Over the past five decades, IBM has made continuous investments in quantum research, specifically the research and design of a full-stack superconducting quantum
computer. However, IBM Quantum's quantum computing strategy is driven by not only a desire to develop a full-stack quantum system but also a desire to advance the entire quantum ecosystem to craft a path to quantum advantage—a path that is defined by the ability to map interesting problems to quantum circuits and the ability to run quantum circuits faster on quantum hardware. Consequently, IBM Quantum is working to make its quantum technology broadly accessible and usable through enterprise adoption and strategic partnerships.

In May 2016, IBM Quantum took its first steps toward advancing the quantum computing industry with the release of an IBM 5-qubit system to the IBM Cloud. This marked the first time that a quantum hardware vendor made a quantum computing system available for public experimentation. Accompanying this release was the introduction of Qiskit. Widely adopted by most quantum hardware and software vendors and quantum cloud service providers today, Qiskit is an open source, hardware-agnostic, software development kit that allows developers to write quantum programs that can be run on quantum computers or quantum simulators. Using Qiskit, developers have access to a circuit library, which includes a comprehensive set of quantum gates and prebuilt circuits and a transpiler that translates Qiskit code into an optimized circuit using a back-end native gate set.

In 2017, IBM began to define its commercially based approach with the release of its client-facing IBM Quantum Network, a premium quantum computing-as-a-service (QCaaS) offering that gave Fortune 500s, academic institutions, government labs, and start-ups access to the most current IBM quantum technology and resources needed to successfully experiment with quantum. The IBM Quantum Network now is made up of over 150 Fortune 500 companies, universities, laboratories, and start-ups. Membership of the IBM Quantum Network is included in IBM Quantum's Premium Plan, available to enterprises as a subscription service. This Premium Plan is one of the three IBM Quantum QCaaS offerings that provide enterprises access to IBM's quantum computing hardware and technical services. In detail:

- **Pay-As-You-Go Plan:** This scaled-down offering is ideal for enterprises and individuals that are still in the early stages of their quantum journey and not yet ready to fully commit to a premium plan. With the Pay-As-You-Go Plan, enterprises gain access to IBM Quantum's 27-qubit Falcon and 127-qubit Eagle systems and simulators, with Qiskit Runtime on an as-needed basis and pay only for the time the quantum resource is dedicated to running the Qiskit program at a rate of $1.60 per second.

- **Premium Plan:** With this subscription, IBM Quantum provides enterprise access to IBM's most advanced systems with shorter wait times and hands-on service. Accessible systems include simulators, exploratory systems, 27-qubit Falcon systems, 127-qubit Eagle systems, and the 433-qubit Osprey system. In addition, enterprises can create and execute quantum programs at scale with Qiskit Runtime, gain hands-on support and training, and curate access to quantum specialists via membership to the IBM Quantum Network.

- **Quantum Accelerator:** Considered to be IBM Quantum's most inclusive premium subscription for enterprises, this full-service offering includes all of the features of premium plan (detailed previously), but with a more personalized approach that includes support plans, and a personalized quantum readiness road map prepared by IBM quantum specialists. With the Quantum Accelerator program, enterprises can expect to build their foundational skills and understanding of quantum, as well as identify key areas for potential quantum value.

To further develop the quantum industry and ecosystem, IBM Quantum has established 36 Quantum Innovation Centers (QIC) worldwide. The IBM QIC provides over 50 industry partners access to
leading-edge quantum compute services, support end users’ quantum research and development, and promote the education and development of the quantum workforce. Comprising the IBM QIC are 7 global computational centers that each house, or will soon house, a dedicated IBM Quantum System One; over 25 quantum hubs through which IBM Quantum provides indirect support to a local set of worldwide partners; and 4 university alliances.

With regard to quantum computing development, IBM Quantum is taking a no-nonsense approach to establishing the utility of quantum computing. This no-nonsense approach includes practical methods that exist today, such as error mitigation, that can be used to craft a continuous path to quantum advantage that results in the delivery of quantum systems that operate at scale, at speed, and with high fidelity by developing quantum processors optimized for performance, error suppression and mitigation techniques to substantially reduce noise and lead to more reliable quantum computations, and middleware that allows for the seamless integration of quantum and classical compute so end users can focus less time on the intricacies of hardware and more time exploring quantum utility.

IBM Quantum’s efforts have resulted in the development of one of the largest fleets (more than 20 in total) of quantum systems accessible to end users and the IBM Quantum Network for experimental purposes from a particular quantum hardware vendor. These systems range in scale and include processors such as the 27-qubit Falcon (2019), the 65-qubit Hummingbird (2020), the 127-qubit Eagle (2021), and the 433-qubit Osprey (2022). IBM’s practical path has also resulted in the release of abstraction tools that end users can leverage to ease the process of estimating and integrating the quantum and classical resources needed to solve problems run on quantum systems. Examples of these execution tools include IBM Quantum’s Quantum Serverless and Circuit Knitting Toolbox.

What’s next for IBM Quantum? As IBM Quantum continues to focus its efforts on crafting a path to quantum advantage, enterprises can expect the continued introduction of scaled quantum technology. With the release of latest IBM quantum development road map in November 2022, IBM announced its plans to realize large-scale quantum computers through the development of modular systems that use both classical and quantum communication to link smaller-size quantum processing units (QPUs). These modular systems will include IBM’s Quantum System Two (to be released online in 2023), the IBM 1,386-qubit Flamingo processor (2024), and the IBM 4,158-qubit Kookaburra processor (2025). In addition, in May 2023, IBM Quantum announced a $100 million partnership with the University of Tokyo and the University of Chicago as the next step for realizing a 100,000-qubit quantum-centric supercomputer by 2033.

IBM Quantum will also continue to develop the quantum ecosystem. Starting in 2024, IBM and the Fundacion Ikerbasque, the Basque Foundation for Science in the Basque Country of Spain, plan to provide Qiskit Runtime Services from a 127-qubit IBM Quantum System One that will be deployed at the IBM-Euskadi Quantum Computational Center. Also during 2024, IBM Quantum plans to open additional IBM Quantum Computational Centers through partnerships with Quebec-based PINQ², the Yonsei University (located in Seoul, South Korea), and the Rensselaer Polytechnic Institute (located in Troy, New York). Currently, IBM Quantum Computational Centers are located in Yorktown, New York (2019); the Fraunhofer Institute, Ehningen, Germany; the University of Tokyo, Shin-Kawasaki, Japan (2021), and the Cleveland Clinic.
**Strengths**

IBM Quantum delivers quantum capabilities that meet the needs of a variety of end users. In addition to the multilayered QClaaS offerings for enterprises, IBM Quantum continues to provide free access to a portion of its quantum systems, specifically 5-, 7-, and 16-qubit QPUs and simulators, available to educators, new learners, and developers seeking to experiment with programming quantum algorithms and running quantum circuits. This open access offering also includes access to an open source library of circuits and ML, optimization, and chemistry algorithms.

For more scientists interested in using the IBM Quantum systems for more advanced scientific research, IBM has introduced four Discovery Accelerators and the Accelerated Discovery Platform for use by select quantum partners (see IBM Accelerated Discovery: A Hybrid Classical and Quantum Compute Platform for Accelerating Science, IDC #US50240523, March 2023). Each Discovery Accelerator brings together scientific expertise and the classical (HPC and AI) and the quantum compute power needed to accelerate scientific discovery for specific research topics. The IBM Discovery Accelerator programs include the IBM-Illinois Discovery Accelerator Institute (2021), Cleveland Clinic-IBM Discovery Accelerator (2021), IBM-Science and Technology Facilities Council (STFC) (2021), and the Quebec-IBM Discovery Accelerator (2022). The IBM Accelerated Discovery Platform provides select IBM Quantum partners access to the quantum technology, tools, resources, and specialists, which are needed to codevelop new use cases related to materials discovery, drug and biomarker discovery, digital health, energy storage, and carbon sequestration.

With many tiers of quantum access and advancements being made to quantum systems, there is the potential for enterprises and end users to lose sight as to which aspects of the IBM Quantum program are relevant to them. To relieve some of this confusion, the quantum hardware vendor makes public the entire IBM Quantum Computing Developmental Roadmap (see IBM Quantum Network Partner Forum, 2023: A Quantum Event for Quantum End Users, IDC #US50726723, May 2023). Updated annually, the IBM Quantum Computing Developmental Roadmap can be used by enterprises to determine what can be accomplished using IBM’s most advanced quantum technology and when.

**Challenges**

Unlike other quantum hardware vendors that provide multiple modes of access to their quantum systems through a combination of their own quantum cloud service and the cloud services of one or more quantum cloud service providers, access to IBM quantum systems is primarily through the IBM Cloud. For a quantum hardware vendor that strives to make quantum computing broadly accessible, not partnering with prominent cloud service providers might sound counterintuitive. Yet the quantum hardware vendor views cloud access as a sandbox environment where both end users and the IBM Quantum team can test and experiment with the current quantum technology. Through this experimentation, the IBM Quantum team can learn more about end-user quantum needs, as well as work to improve and advance the developmental status and utility of its quantum computing technology. In doing so, IBM provides access to over 20 systems, which results in very little downtime for the IBM quantum customer.

However, IBM Quantum is not opposed to partnering with other cloud service providers. For example, in 2021, IBM Quantum announced a partnership with quantum computing platform start-up, Strangeworks. Through this partnership, IBM quantum simulators and systems were integrated in the Strangeworks platform. As a result, end users can now access IBM quantum through a cloud platform other than the IBM Cloud. More recently, IBM Quantum announced plans to open its first European-based quantum datacenter at the IBM facility in Ehningen, Germany. Expected to be fully operational
in 2024, the IBM European-based quantum datacenter will provide cloud-based access to multiple IBM quantum systems made up of more than 100 qubits. In doing so, IBM must be able to partner with cloud service providers located throughout Europe to route quantum and classical workloads across geographies while also ensuring compliance with European data regulation requirements and privacy laws across different geographical regions. It is likely that more announcements and partnerships are forthcoming, which will make the IBM quantum systems even more accessible.

**Consider IBM Quantum When**

The IBM Quantum QClaaS offering provides value to enterprises and end users regardless of where they are in their quantum computing journey. By having access to the IBM quantum tools, resources, and specialists early in the quantum journey, enterprises can prioritize quantum experimentation, specifically identifying quantum use cases and writing quantum algorithms, and worry less about having to invest in in-house quantum specialists and skills training until they are confident that quantum is right for them. As a member of the IBM Quantum Network, customers find value in the ability to collaborate with other industry partners. Not only does this help establish relationships, but it also helps enterprises become knowledgeable about other industry-relevant quantum research, implementation challenges, and success stories. Finally, because IBM Quantum is transparent about how the company is crafting its path to quantum advantage, enterprises can have confidence that the resources and funding invested in IBM Quantum aligns with current and future company goals.

Enterprises that are interested in working with quantum specialists with domain knowledge and want access to resources that will allow them to start experimenting with small-scale systems to learn quantum but have the flexibility to expand to the use of larger-scale systems for solving more complex problems should consider IBM Quantum.

**APPENDIX**

**Reading an IDC MarketScape Graph**

For the purposes of this analysis, IDC divided potential key measures for success into two primary categories: capabilities and strategies.

Positioning on the y-axis reflects the vendor's current capabilities and menu of services and how well aligned the vendor is to customer needs. The capabilities category focuses on the capabilities of the company and product today, here and now. Under this category, IDC analysts will look at how well a vendor is building/delivering capabilities that enable it to execute its chosen strategy in the market.

Positioning on the x-axis, or strategies axis, indicates how well the vendor's future strategy aligns with what customers will require in three to five years. The strategies category focuses on high-level decisions and underlying assumptions about offerings, customer segments, and business and go-to-market plans for the next three to five years.

The size of the individual vendor markers in the IDC MarketScape represents the market share of each individual vendor within the specific market segment being assessed.

**IDC MarketScape Methodology**

IDC MarketScape criteria selection, weightings, and vendor scores represent well-researched IDC judgment about the market and specific vendors. IDC analysts tailor the range of standard characteristics by which vendors are measured through structured discussions, surveys, and
interviews with market leaders, participants, and end users. Market weightings are based on user interviews, buyer surveys, and the input of IDC experts in each market. IDC analysts base individual vendor scores, and ultimately vendor positions on the IDC MarketScape, on detailed surveys and interviews with the vendors, publicly available information, and end-user experiences in an effort to provide an accurate and consistent assessment of each vendor’s characteristics, behavior, and capability.

**Market Definition**


**Quantum Computing Systems**

As defined by IDC, quantum computing is expected to be an industry disruptor that will revolutionize organizations’ ability to solve intractable problems and lead them to a competitive advantage through the realization of a *quantum advantage*. Quantum advantage is defined by IDC as having the ability to solve a problem that has actual value to a business, humanity, or otherwise. Quantum advantage differs from *quantum supremacy*, which is defined as the ability to use quantum computing to solve a problem that cannot be solved using a classical computer. The term *quantum supremacy* is losing momentum because unsolvable problems do not necessarily provide value to an end user.

The complex problems best suited for quantum computing are those problems that can be solved faster, more accurately, and more cost efficiently because of the quadratic speedup, which only a quantum computing system will be able to deliver. These problems include simulations of nature, optimization, and algebraic/factorization problems. To solve these complex problems, quantum compute systems must rely on the quantum mechanics of superpositioning and entanglement of qubits to perform quantum computations.

Unlike a classical compute system that is made up of bits that are characterized by well-defined states of 0 and 1, the building blocks of quantum compute systems are qubits that theoretically can hold an unlimited number of states: 0, 1, or any value in between. This property is referred to as the qubit’s superposition state. The superposition state is unknown until the qubit is measured. Once measured, the qubit falls out of its superposition state. Quantum computations involve at least two entangled qubits that are connected or linked via their superposition state. A change in the state of one qubit results in a simultaneous, predictable change in the state of its entangled pair. Combined, the quantum properties of superpositioning and entanglement provide qubits the ability to process more data faster, more cost effectively, and better (more accurately or precisely) than a classical computer.

Quantum computing systems can be categorized into two types: digital and analog. Digital quantum computing systems can be programmed using algorithms. Comparatively, while some parameters of a problem can be programmed using an analog quantum computing system, the majority of the problem is solved by simulating the problem using the natural system of the qubit.

Types of quantum computing systems include circuit or gate-based quantum computing systems (superconducting quantum computers, trapped-ion quantum computers, neutral atom quantum computers, spin-based quantum dot quantum computers, and dopants/vacant quantum computers), measurement-based quantum computing systems (photonic quantum computers), quantum annealing computing systems, and topological quantum computing systems.
Circuit (Gate-Based) Quantum Computing Systems

Circuit (or gate-based) quantum computing systems perform quantum computations by taking classical input data and transforming it into quantum circuits using a series of discrete gate operations and measurements, referred to as quantum algorithm. More specifically, quantum circuits are made up of quantum gates that are represented by unitary matrices — referred to in linear algebra as complex square (2 x 2 or 4 x 4) matrices with orthonormal rows. The unitary matrices operate on a small number of (1-2) qubits whose superposition state is represented by a vector. When applied to qubits, the result is a 1- or 2-qubit gate. The 1-qubit gate results in a spin, and the 2-qubit gate results in a pair of entangled qubits. The 1- and 2-qubit gate sets represent the universal gate sets needed to perform quantum computations. Measuring the quantum state of the entangled qubits will cause them to flatten back to a binary state. Several types of quantum modalities are considered to be circuit (gate-based) quantum computing systems including:

- Superconducting quantum computing systems
- Trapped-ion quantum computing systems
- Neutral atom quantum computing systems
- Spin-based quantum dot systems
- Dopants/vacant quantum computing systems
- Photonic quantum computing systems

Quantum Computing Platforms and Technologies

Quantum computing platforms and technologies are made of foundational or derivative hardware, software, or hardware plus software platforms and technologies that are used to build a system or to consume or interface with a core quantum computing system (aka a quantum computer). Types of quantum computing platforms and technologies include quantum algorithms, quantum software development kits, quantum middleware, and other quantum computational platforms that are runtime environments that provide end-user access to cloud-based quantum computing systems.

Quantum Computing Provisioned Services

Quantum computing is primarily consumed via provisioned services (aka cloud) — either a quantum vendor's own public cloud, a dedicated cloud, or a public cloud that provides access to multiple quantum technology vendors. Some vendors provide actual quantum computing hardware.

Quantum computing infrastructure-as-a-service (QCIaaS) offerings consist of all the cloud-based premium platform offerings, and services organizations need to exploit the compute functionality of quantum computers offered by a specific quantum hardware vendor via the quantum hardware vendor's cloud service and delivered directly to the end user. Through these offerings, organizations can reserve time on a quantum computing vendor's most current and advanced quantum technology for a fee. QCIaaS platforms offer low-level latency connectivity between the quantum processing unit and the end-user's high-performance classical hardware. Network APIs integrate with multiple classical resources and provide access to core operating functions such as user authentication, system service authorization, circuit submission, memory management, and concurrency. In addition, QCIaaS offerings can include quantum training and support, access to quantum specialists and a network of industry partners, quantum software development kits designed to help developers write applications, and quantum algorithms, as well as enable IT developers to run pulse-level and gate-level descriptions of the quantum circuit.
Quantum computing platform as a service (QCPaaS) is offered only as public cloud solutions sold directly from cloud service providers. These premium cloud-based services offered by cloud service providers give organizations access to multiple vendors’ quantum hardware and software and the developmental tools needed to experiment with quantum programming, as well as access to quantum specialists with both domain and technical expertise. In addition, QCPaaS offerings provide the necessary training and skills development tools that enterprises can use to educate current and future IT developers while also equipping scientists and students with technology to experiment with. Further, QCPaaS offerings provide a unique opportunity for native integration with classical supercomputing and AI capabilities in the same cloud, easing the integration process.

Independent software vendors (ISVs) deliver quantum computing software as a service (QCSaaS)-specific, quantum-ready, and hardware-agnostic applications and services to help solve organizational or business problems. These workload-based applications and services include algorithms that deliver a quantum advantage to businesses and organizations. QCSaaS applications and services provide the syntax, or instructions, required for algorithm design and optimization; compilers used to analyze and map quantum algorithms to quantum hardware; and additional programming needed for error correction, characterizing circuits, and so forth. By using QCSaaS solutions, organizations seek to achieve a competitive advantage.

Like traditional SaaS applications, the code or intellectual property of the service is typically owned by the SaaS ISV (see IDC’s Worldwide Performance-Intensive Computing Taxonomy, 2022, IDC #US48845922, February 2022). These new models provide organizations with access to and consumption of software and application functionality built specifically for network delivery and hosted, provisioned, and accessed by users over the internet.

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Related Research

- **Worldwide Quantum Computing Forecast, 2023-2027: Surfing the Next Wave of Quantum Innovation** (IDC #US49198322, August 2023)
- **IDC TechBrief: Applying Post-Quantum Cryptography to Data Protection to Enhance Digital Trust** (IDC #US50789923, June 2023)
- **Tunnel Falls: Intel’s First QPU Release to the Research Community** (IDC #IcUS50901523, June 2023)
- **IBM and the University of California, Berkely, Demonstrate Evidence of Quantum Utility and Possible Near-Term Advantage** (IDC #IcUS50873123, June 2023)
- **Expanding the Quantum Ecosystem with Opening an IBM European Datacenter** (IDC #IcUS50832923, June 2023)
- **IBM Quantum’s Path to Quantum Utility Through a $100 Million Partnership and the Development of a 100,000-qubit Quantum-Centric Supercomputer** (IDC #IcUS50753723, May 2023)
- **IBM Quantum Safe Roadmap and Quantum Safe Technologies and the Urgency to Become Quantum Resilient** (IDC #IcUS50663223, May 2023)


Microsoft's Quantum Computing Strategy: A Pragmatic Approach to Quantum Advantage (IDC #US50562323, April 2023)

D-Wave: The Second Publicly Traded Quantum Start-Up at Risk of Being Delisted (IDC #US50523723, March 2023)

Rigetti Computing: Is This the Story Where David Loses and Goliath Wins? (IDC #US50467423, March 2023)

Post-Quantum Cryptography End User Adoption Trends, 2023 (IDC #US50033523, February 2023)

A Note on the Q2B22 Silicon Valley Conference: Quantum Investment Outlook (IDC #US50009423, January 2023)

Synopsis

This IDC study provides an assessment of worldwide quantum computing hardware vendors through the IDC MarketScape model.

"Quantum computing is a nascent technology, and the quantum computing market is made up of numerous companies developing quantum computing hardware. However, quantum computing hardware is only useful if there are tools and resources that enable end users to experiment with the technology," said Heather West, research manager, Quantum Computing. "QCaaS offerings provide end users access to the hardware, software, quantum specialists, and other tools and resources needed to experiment with quantum, but not all offerings include the same features. Customers should consider partnering with quantum hardware vendors that provide the quantum hardware, software, tools, resources, and expertise that match both their quantum needs and their stage in their quantum journey."
About IDC

International Data Corporation (IDC) is the premier global provider of market intelligence, advisory services, and events for the information technology, telecommunications and consumer technology markets. IDC helps IT professionals, business executives, and the investment community make fact-based decisions on technology purchases and business strategy. More than 1,100 IDC analysts provide global, regional, and local expertise on technology and industry opportunities and trends in over 110 countries worldwide. For 50 years, IDC has provided strategic insights to help our clients achieve their key business objectives. IDC is a subsidiary of IDG, the world's leading technology media, research, and events company.

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