Quantum Computing: Industry Developments

Gregory LaRocca, Office of Industries

This EBOT provides an overview of quantum computing (QC) and industry developments. A future working paper will explore QC's capabilities, applications, and international trade impacts. Firms launched QC cloud services that employ an Infrastructure as a Service (IaaS) business model. QC is an emerging technology that is currently in a testing and development phase, but research firms forecast that QC will significantly impact the transport, logistics, chemicals, and pharmaceutical industries over the next few years. QC may become an important competitiveness factor for industries that embrace the technology and cloud-service providers.

What is quantum computing?

Quantum computing is a branch of computing that uses the principles of quantum mechanics—matter and energy at the atomic and subatomic level—to compute data. Conventional computing uses binary digits—represented in two observable states (e.g., 0 or 1)—to perform calculations. In contrast, QC uses quantum bits (qubits)—that may exist in two observable states or a third unobserved state—to perform calculations.[1] A qubit's unobserved state allows QC to explore multiple variations in a single calculation simultaneously. As a result, QC solves computationally complex problems significantly faster than conventional computers. Table 1 outlines some problem types that QC may answer.

Table 1: QC capabilities and example uses

Simulating complex systems	**Solving combinatorial problems**	**Optimizing performance**
QC simulates the material behavior at the atomic level. As such, QC may model the behavior of new metal alloys or chemical compounds.	QC running linear algebra may solve complex problems faster than conventional computers.	QC may allow firms to plan production cycles to maximize output.
Example use: Daimler AG and IBM applied QC to model next-generation lithium-sulfur batteries for electric vehicles.	***Example use:*** Google's Researchers used QC to solve a problem in 200 seconds that would have taken state-of-the-art conventional computers 10,000 years.	***Example use:*** DENSO and D-Wave reduced industrial robot wait time by 15 percent with QC. Volkswagen is developing QC capacity to lessen travel times and vehicle congestion.

Sources: Arute et al., "Quantum Supremacy Using a Programmable Superconducting Processor," October 2019; Biondi et al., "Quantum Computing," December 14, 2021, 17-18; Garcia, "IBM and Daimler Use Quantum Computer," January 8, 2020; D-Wave Systems Inc., "Quantum Computing in Manufacturing & Logistics," accessed May 23, 2022; Volkswagen AG, "Quantum Computers," November 5, 2019.

What is the business model for QC?

QC uses an Infrastructure as a Service (IaaS) business model whereby firms provide their services directly or through an intermediary. Several leading technology companies—such as Alibaba, Amazon, Google, IBM, and Microsoft—offer quantum computing as a service (QCaaS) platforms that connect users to QC resources.[2] Today's QC resources are in an early development stage.[3] McKinsey analysts believe the technology will achieve fault-tolerance and allow users to operate thousands of qubits between 2025 to 2030.[4] Hyperion Research estimates the QC market will reach $830 million by 2024.[5]

---

[1] The unobserved state is known as superposition. For more information on superposition or other quantum phenomena, see "Explainer: What Is a Quantum Computer?"

[2] QCaaS platforms may contract services with QC hardware firms. QCaaS platforms charge up to $900 per compute hour, but platforms offer deep discounts for learners.

[3] Today's QC has high error rates, which make QC calculations unreliable. Correcting theorems may lower error rates, but these theorems would require more qubits and new technologies.

[4] Biondi et al., "Quantum Computing," December 14, 2021, 4, 19.

[5] Sorenson and Joseph, "Key Takeaways from QC Market Study," October 2020.

What fields exist within QC?

The following are distinct fields within QC: hardware, software, and algorithms.[6] QC hardware firms make quantum computers or components thereof. Table 2 identifies certain QC hardware firms and their technological pathways. QC software firms design the back-end architecture and programming resources. Finally, QC algorithm firms specialize in programming models to address business-specific questions.

Table 2: QC firms researching hardware, headquarters country, and hardware approaches.

Firm	Country	Hardware approach
Alibaba Damo	China	Superconducting circuits
D-Wave	Canada	Superconducting circuits
Google Quantum AI	USA	Superconducting circuits
Honeywell	USA	Trapped-ion chips
IBM	USA	Superconducting circuits
Intel and QuTech	USA and Netherlands	Silicon spin qubits
ionQ	USA	Trapped-ion chips
Oxford Quantum Circuits	United Kingdom	Superconducting circuits
Pasqal	France	Neutral rubidium atom registers
Rigetti	USA	Superconducting circuits
Quantum Circuits, Inc.	USA	Superconducting circuits
Xanadu	Canada	Photonic modules

Source: Staff research based on information presented on company websites.

What companies are leading research in QC?

The leading-edge QC hardware firms stand to benefit disproportionately. For example, the first QC hardware firm to develop fault-tolerant and scalable QC may set the standards and receive a lengthy backlog of potential projects. Likewise, firms that adopt QC early may have an advantage over their peers due to improved R&D processes, supply chain management, and production optimization.

It is difficult to predict which firms may be the first to provide fault-tolerant quantum cloud services. At the moment, the QC leaders are IBM and Google, which reported operating quantum computers with the highest number of qubits—127 and 53 qubits, respectively. Beyond qubits, the size of public cloud service markets may indicate potential end markets; the largest markets in 2016 were the United States, EU, China, and Brazil. Also, QC patent applications by country show which countries are driving research: the U.S., with 1,094 patent applications; China, with 384 patent applications; and Japan, with 305 patent applications.[7] While U.S.-based firms appear to lead, the race to be the first QCaaS provider is ongoing.

Sources: Biondi et al., *Quantum Computing: An Emerging Ecosystem and Industry Use Cases*, December 14, 2021; Bova, Goldfarb, and Melko, "Quantum Computing Is Coming. What Can It Do?," July 16, 2021; Congressional Research Service*, Emerging Military Technologies: Background and Issues for Congress*, April 6, 2022, Gibney, "Quantum Gold Rush," October 2, 2019, 22–24; Giles, "Explainer: What Is a Quantum Computer?," January 29, 2019; Horowitz, and Grumbling, *Quantum Computing*, 2019; Ménard et al., "A Game Plan for Quantum Computing," February 2020; Mason, "Trends in Quantum Computing Patents," May 24, 2021; Neven, "Computing Takes a Quantum Leap Forward," October 23, 2019; and USITC, *Global Digit Trade 1*, August 2017; and Sorenson and Joseph, "Key Takeaways from QC Market Study," October 2020.

[6] While firms may specialize in a particular QC field, many QC firms are multi-disciplinary. For instance, a QC hardware firm may distribute its proprietary software tools. Also, QC hardware firms may provide direct access to QC services or indirect access through QCaaS platforms.

[7] Mason, "Trends in Quantum Computing Patents," May 24, 2021.