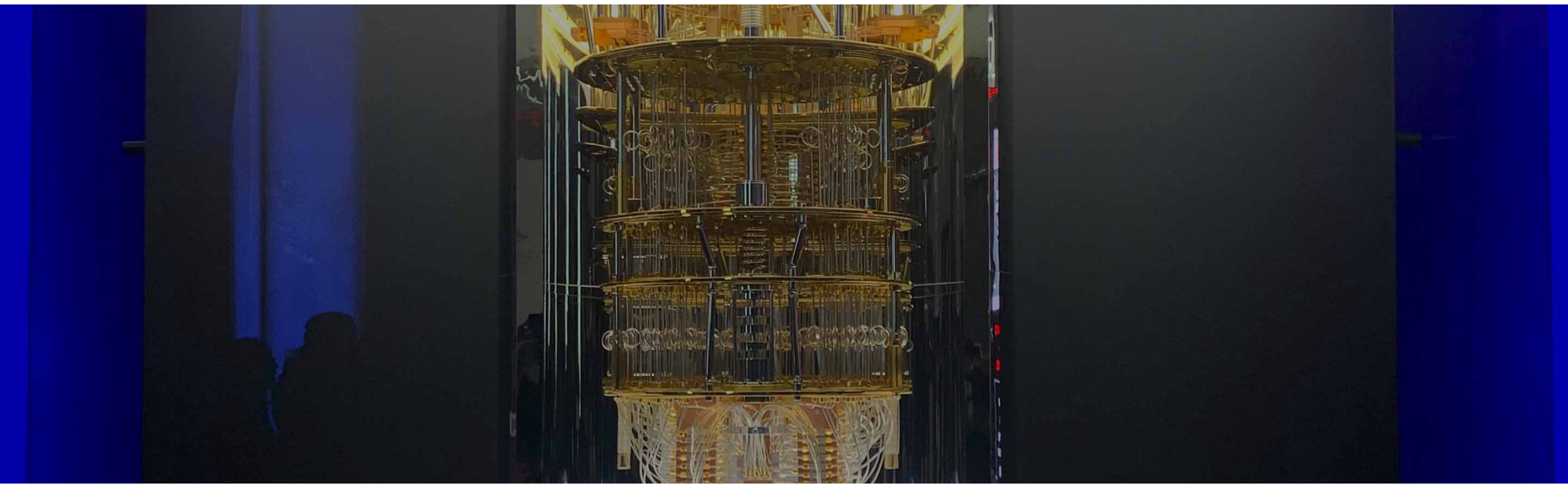
KEARNEY 100



Quantum computing: what's coming and what it means for Japanese companies

Technology / Article
April 07, 2025

Are Japanese companies ready to take advantage of the next evolution in quantum computing?

As quantum computing technology providers continue to make significant strides in boosting the technology's capabilities and performance, it's important for companies—particularly in the chemicals and energy industries—to understand how quantum computing will likely unfold over the next decade, what it will be capable of, and how companies could harness the technology to help transform their businesses.

Introduction

Quantum computing is increasingly making headlines, generating multi-industry interest and garnering significant investment. Heavy hitters have publicized major strides, from Google Quantum AI announcing the realization of quantum error correction to QuEra heralding the execution of algorithms on a quantum computer equipped with 48 logical qubits and IBM introducing the Heron processor capable of performing 100 million operations. Academia is also in the game, with the University of Tokyo sharing its decision to install a quantum computer running IBM's state-of-the-art Eagle processor to boost research capabilities.

Despite its futuristic name, quantum computer development is quite contemporary and is already at a stage of intense international technological competition. More than 40 companies are engaged in developing quantum computer technology, including tech giants Google, IBM, and Microsoft, as well as rapidly growing high-tech ventures Rigetti, OQC, IonQ, Quantinuum, and QuEra. According to *The Quantum Insider*, investors allocated $2.2 billion USD, with governments contributing an additional $25–30 billion USD, to quantum technologies in 2022. This intense race, backed by enormous investments, has led to exponential improvements in the performance of quantum computers.

However, quantum computers are still in a developmental stage and face several technical barriers before they can be fully commercialized. Thus, predicting their growth accurately is challenging. But with their potential for non-linear innovation, quantum computers will impact multiple industries, including chemistry, materials, energy, pharmaceuticals, electronics, and heavy industries—key areas of Japan's economy.

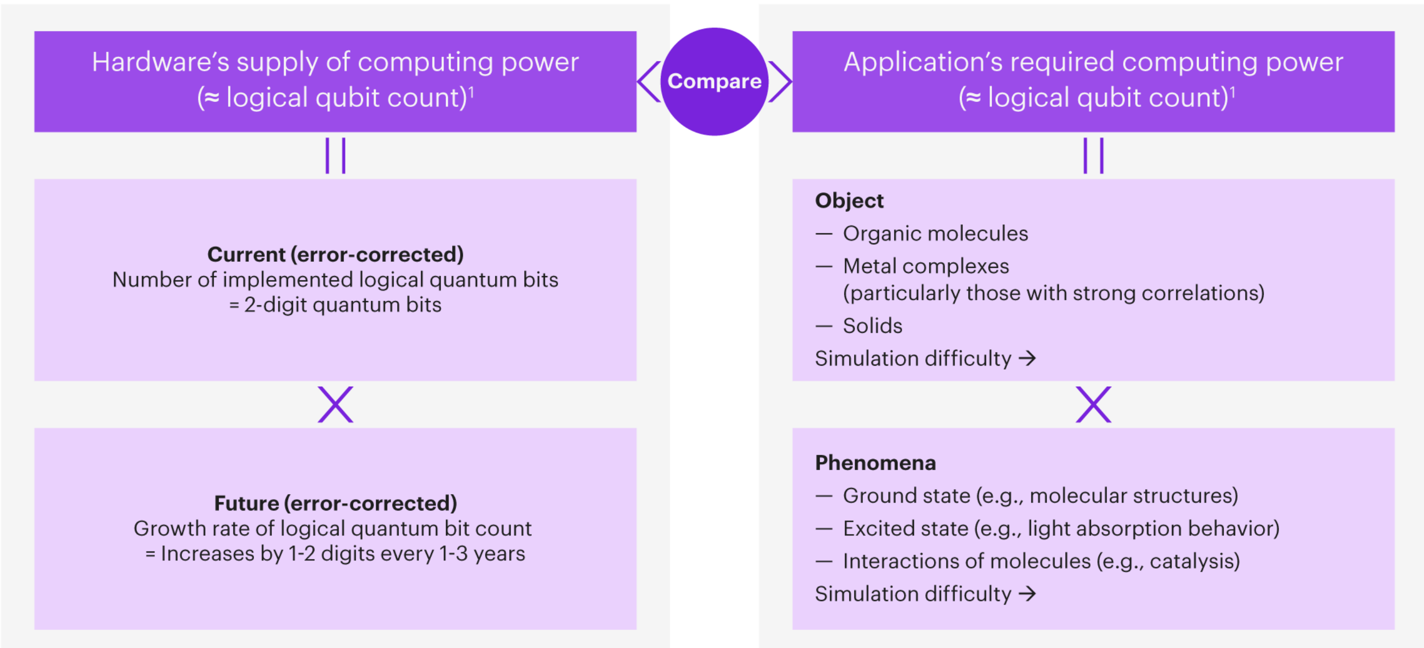
In this report, we will estimate the speed of technological advancements in quantum computing, focusing on the fields of chemistry, materials, and energy. We will also explore potential use cases for quantum computers and suggest how manufacturers and users should prepare for their emergence.[1]

Evolution of quantum computer hardware

To predict the emergence of use cases for quantum computers over time, our approach, shown in figure 1, involves simulating the computing power that quantum computer hardware will supply over time and comparing it with the computing power required for various use cases. Based on this, we predict the timeline for the emergence of these use cases.

Figure 1

The method for forecasting quantum computer use cases involves simulating the computing power over time and comparing it with the computing power required for various use cases



[1] The actual supply of computing power is affected by factors of the hardware in addition to logical qubit count (such as the fidelity of physical qubits, the clock speed of calculations, etc.). In this report, the logical qubit count is used as a simple indicator for ease of understanding.

Source: Kearney analysis

Quantum computers, which perform computations by manipulating "quanta," can be categorized into several types based on the type of quantum system they use. The most common type today is the superconducting quantum computer, which is being developed by major companies IBM and Google's Quantum AI, as well as emerging players Rigetti and Oxford Quantum Computing. Other methods include ion traps (IonQ, Quantinuum), photons (PsiQuantum), electron spins (Intel), topological qubits (Microsoft), and neutral atoms (QuEra). Each method has its advantages and disadvantages regarding error rates, scalability, and physical footprint, with no single approach emerging as the industry standard yet.

Quantum computer performance has been improving exponentially. For instance, IBM's quantum computer grew from Falcon (27 qubits in 2019) to Condor (1,121 qubits in 2023), increasing by two orders of magnitude in four years. IBM aims to achieve between 10,000 and 100,000 qubits by 2026. Similarly, IonQ measures performance using algorithmic qubits (#AQ) and has increased its performance from Harmony (#AQ 9 in 2020) to Forte Enterprise (#AQ 30 in 2023), with a goal of reaching #AQ 1024 by 2028.

In our analysis, considering performance trends of other quantum computer manufacturers and interviews we conducted, we assume that:

1. Quantum computers with double-digit logical qubits are currently available in 2024.
2. Performance will increase by an order of magnitude approximately every one to three years.

While the number of physical qubits is often used as a reference point, it is not a perfect measure due to error rates. As such, quantum error correction is required, and a single logical qubit is typically expressed using multiple physical qubits. Although the number of logical qubits is widely used as a benchmark, it does not directly represent the overall performance of a quantum computer. Nevertheless, given its accessibility and commonality as a benchmark, we use logical qubits as a performance indicator for the purposes of this report.

Applications of quantum algorithms

Promising applications for quantum computers in the chemistry and pharmaceutical industries include quantum chemical calculations, sensing, and machine learning. The fields of chemistry, materials, and energy focus on quantum chemical calculations and machine learning applications; accordingly, in this report we will primarily consider quantum chemical calculations.

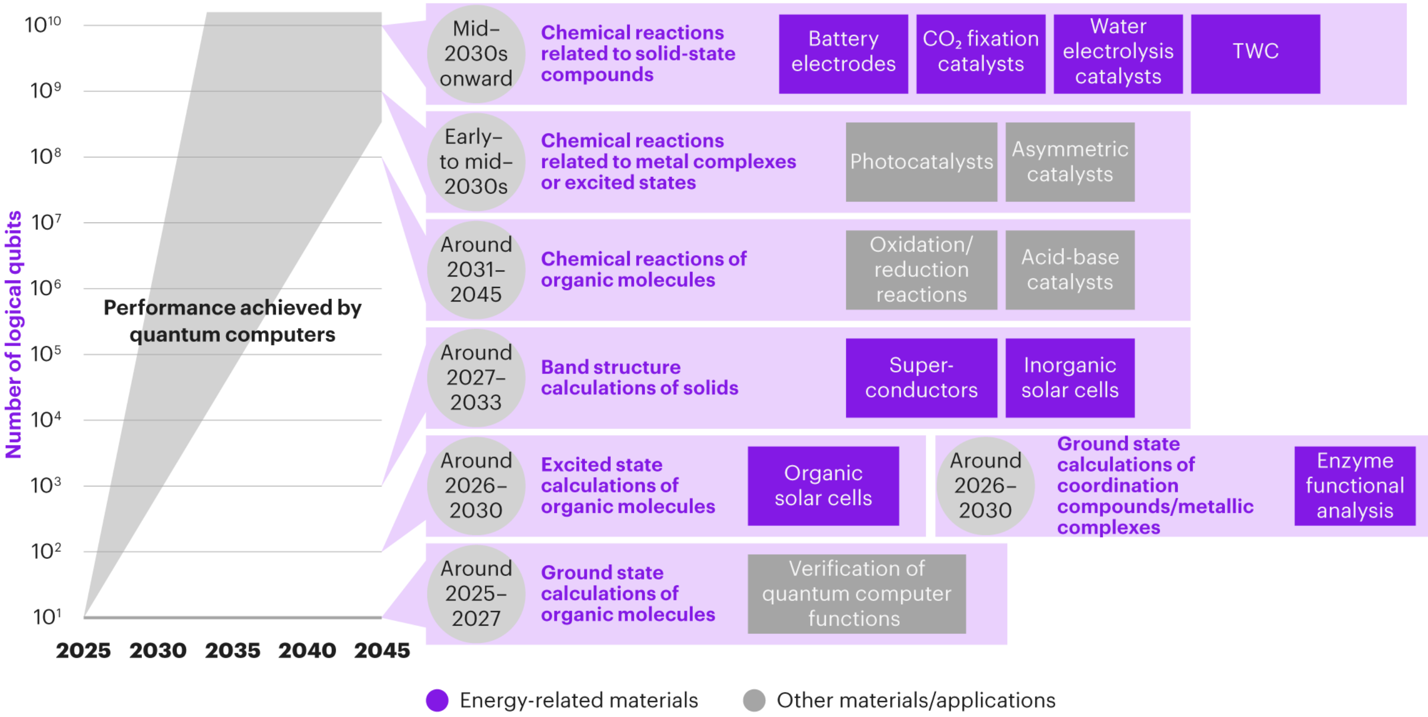
Quantum chemical calculations simulate the behavior of chemical compounds and their reactions. Quantum computers are well-suited for these calculations because many chemical phenomena are governed by the behavior of electrons, which follow the principles of quantum mechanics—similarly to how quantum computers operate.

The performance required for quantum chemical simulations depends on two factors: the simulated object and the simulated phenomena. Objects can be classified into organic molecules, metal complexes, and solids, in order of increasing difficulty. The phenomena can be divided into ground states, excited states, and interactions of molecules, again increasing in difficulty in that order. The performance needed for these simulations varies greatly depending on the algorithms and the specific quantum computer used. Additionally, hybrid methods combining quantum and classical computers are actively being researched.

Forecast results

Our findings, based on the evolution of quantum hardware and the performance required for specific applications, are summarized in figure 2.

Figure 2
Quantum computer performance shows exponential evolution and application expansion



Source: Kearney analysis

The first likely application to emerge within the next three years is calculating the ground states of small organic molecules. While classical computers can already perform this with high accuracy, demonstrating that quantum computers can simulate real molecules would provide proof of their capabilities, accelerating investments and technological development.

By the late 2020s, we expect quantum computers to be able to calculate the ground states of metal complexes, which could have applications in energy—for example, the development of artificial catalysts for ammonia synthesis based on studies on ground states of nitrogenase, which is a natural catalyst that converts nitrogen into ammonia. The impact could be limited at this stage as the understanding of interactions between the catalyst and reacting molecules is crucial to design the effective artificial catalyst. On the other hand, the excited states of organic small molecules are expected to become analyzable around the same period. This could lead to breakthroughs in areas such as improving the efficiency of organic solar cells or analyzing dye behavior.

From the mid-2020s to the mid-2030s, quantum computers may extend their applications to more complex solid-state simulations. Specifically, they could be used to analyze materials such as superconductors, inorganic solar cells, batteries, and fuel cells. This would enable the selection of elements and additives, as well as structural optimization, to improve performance.

The use of quantum computers for analyzing chemical reaction mechanisms is expected to emerge by the early 2030s. Among various applications, the analysis of catalytic reactions involving solid-state materials is considered the most vital, particularly in the energy sector. This is because many of the key technological challenges in the field—such as improving hydrogen production, enhancing carbon capture, and optimizing battery charging/discharging efficiency and lifespan—are centered around (typically solid-gas or solid-liquid) catalysis. In fact, numerous players in the quantum computing space, such as Quantinuum-BMW-Airbus (fuel cells) and Daimler in collaboration with Google and IBM (LIB electrodes), have already started targeting catalyst-related applications. This highlights the anticipated high impact of these developments.

Another intriguing application expected to emerge around the same period is in the field of nuclear fusion. In major fusion methods such as the Tokamak and FRC, plasmas (for example, hydrogen) are confined in extremely small spaces using magnetic fields. During this process, the plasma itself generates magnetic fields, resulting in complex interactions that must be accounted for in simulations. While accurately simulating these interactions is challenging for classical computers, quantum computers could handle these complexities more effectively.

Figure 3 illustrates several potential economic impacts from improvements in quantum computer performance. This report exemplifies expected applications limited to the energy sector, but even so, it is evident the impact spans a wide range of industries, from materials and chemicals to machinery and heavy industry. Below, we highlight two examples and elaborate on quantum computers' impact.

Figure 3

Several potential economic impacts could be realized through improvements in quantum computer performance

Manufacturing

Improvement of solar cell efficiency

- Simulating semiconductor and electrode energy states under various conditions.
- Compared to simulating chemical reactions, it is assumed that the difficulty is relatively lower because there is no need to observe the behavior of materials over time.

Example:
Solar cell efficiency improvement cost-reduction effect: about ¥20 billion/year

Improvement of nuclear fusion efficiency

- Simulating complex plasma behavior.
- The simulation method itself is still in the developmental stage, and it is necessary to track temporal changes, which is assumed to involve a high level of technical difficulty.

Example:
Cost-reduction effect in fusion reactor manufacturing: several billion yen/reactor

Storage/conversion

Catalyst for fuel synthesis (for hydrogen production, CO_2 fixation, ammonia synthesis, etc.)

- Simulating solid catalysis to improve reaction efficiency.
- It is necessary to track the time-dependent behavior of solids containing transition metals, which involves a high level of technical difficulty.
- Catalysts containing metal oxides, in particular, would present a high level of difficulty.

Example:
Water electrolysis cost reduction effect: about ¥40 billion/year

Improvement of secondary battery efficiency

- Reduction in development costs for materials, especially those related to electrodes
- The technical difficulty is comparable to that of "catalyst for fuel synthesis."

Example:
Secondary battery production cost-reduction effect: about ¥60 billion/year

Transportation

Realization of high-temperature superconductivity

- Simulation of electron behavior in solids aimed at achieving high-temperature superconductivity.
- It is assumed that the difficulty is relatively low because there is no need to handle the time-dependent changes of the material itself.

Example:
Transmission cost-reduction effect: about ¥60 billion/year

Utilization

Fuel cells

- Reduction in development costs for materials, especially those related to electrodes
- The technical difficulty is comparable to that of "catalyst for fuel synthesis."

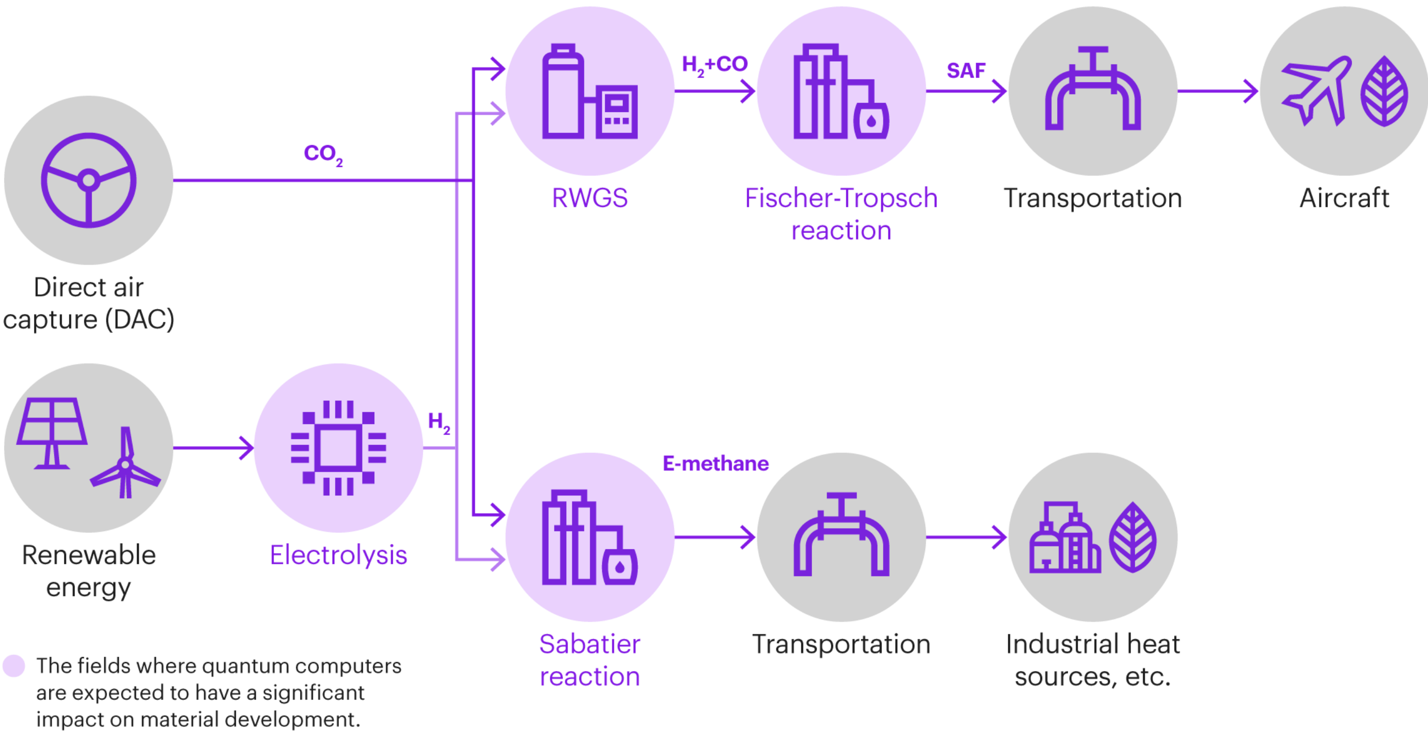
Example:
Fuel cell stack cost-reduction effect: about ¥30 billion/year

Source: Kearney analysis

Case study 1: Green fuel

Green fuels—specifically SAF (sustainable aviation fuel) and e-methane—are produced by reducing CO_2 (see figure 4). SAF is gaining traction due to regulations aimed at significantly reducing CO_2 emissions from aviation fuel. The domestic market for SAF is projected to grow rapidly, reaching ¥500 billion by 2030 and ¥2.3 trillion by 2050. Currently, most SAF is produced from plants, but there are limitations due to the high cost of water and land for cultivation and restricted production capacity. This has led to increasing attention to power-to-liquid (PtL) technology, which uses hydrogen produced from water electrolysis and CO_2 captured through direct air capture (DAC) to produce fuel. However, PtL is still more expensive than plant-based SAF, creating an adoption bottleneck.

Figure 4
Value chain of sustainable aviation fuel and e-methane



Source: Kearney analysis

E-methane, a green-fuel methane produced by reducing CO_2 with hydrogen, is primarily expected to serve as an industrial heat source. However, like SAF, the high cost has slowed its adoption. Once the fuel is introduced, the domestic market for e-methane is expected to grow to ¥29.4 billion by 2030 and ¥1.6 trillion by 2050.

In both cases, cost remains the limiting factor, and catalysts used in water electrolysis and CO_2 fixation play a key role in cost reduction. A large portion of the operational costs (opex) of green fuel production stems from the cost of renewable energy. Improving catalysts' energy conversion efficiency is expected to help reduce opex. For instance, the energy conversion efficiency of methane production is around 50 to 60 percent, with room for improvement. Catalysts also account for a significant portion of capital expenditure (capex), especially in water electrolysis systems. For example, in alkaline water electrolysis, about 50 percent of the cost comes from electrodes. Quantum computing is expected to play a role by enabling precise quantum chemistry simulations to improve energy conversion efficiency and reduce the amount of precious metals or catalysts used, thus reducing both opex and capex.

We can estimate the impact of quantum computing on renewable fuel production. According to Japan's Hydrogen Basic Strategy of 2023, Japanese companies are expected to introduce 15 GW of water electrolysis equipment by 2030. Given an equipment cost of ¥380,000 per kW (based on 2019 demonstration data), this corresponds to about ¥5.7 trillion. Since electrodes account for roughly 50 percent of this cost (¥2.9 trillion), a 10 percent reduction enabled by quantum computing would save ¥290 billion. Distributed evenly between 2024 and 2030, this would create an annual value of about ¥42 billion from water electrolysis alone. As for opex, the domestic market for SAF and e-methane is expected to reach ¥530 billion by 2030 and ¥3.9 trillion by 2050. Since about 50 percent of the cost comes from renewable energy, and assuming a 10 percent improvement in energy conversion efficiency through quantum computing, cost savings of ¥25 billion by 2030 and ¥190 billion by 2050 could be achieved. In total, the cost-saving potential of quantum computing in renewable fuel production could reach ¥100–200 billion by 2030, mainly centered around SAF, and multiplied several times by 2050 with the addition of e-methane.

Case study 2: Nuclear fusion

Nuclear fusion is attracting attention as a form of renewable energy with a low risk of accidents and minimal high-level radioactive waste, with a global market projected to be in the tens of trillions of yen. Several methods of nuclear fusion exist, including Tokamak fusion, laser fusion, and field-reversed configuration (FRC), but controlling plasma with magnetic fields and developing reactor materials (such as radiation-resistant blankets) remain technical challenges, especially in Tokamak and FRC.

Quantum algorithms are expected to help address design challenges by refining and accelerating plasma simulations, particularly with issues such as reactor shape and magnetic field configuration. In Tokamak fusion, for instance, plasma is confined with a magnetic field, but the plasma itself generates its own magnetic field, creating complex interactions. Simulating these interactions is difficult with classical computers, but quantum computing holds promise in this area.

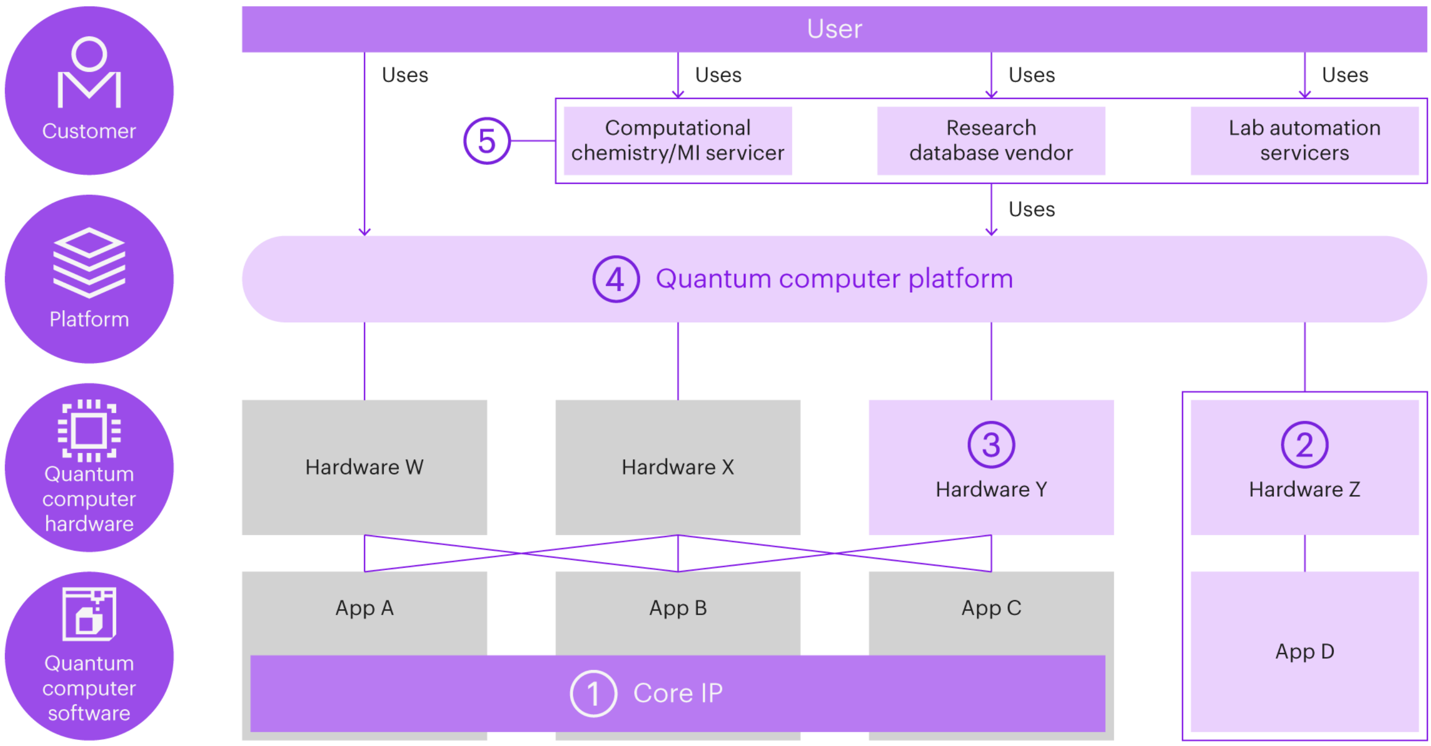
The investment in nuclear fusion facilities is about ¥1 trillion per unit, and even a 1 percent improvement in performance through quantum computing could lead to cost savings in the tens of billions of yen per unit. Moreover, since nuclear fusion experiments are expensive, quantum simulations could significantly reduce the number of experiments needed. Japan, in particular, has high renewable energy costs compared to other countries, and early adoption of nuclear fusion is expected to become economically viable. By the latter half of the 21st century, nuclear fusion could supply 18 to 26 percent of total electricity in Japan, and cost savings from its introduction could reach approximately $10 billion per year. This makes quantum computing a valuable application for Japan, which could benefit from an expanded portfolio of renewable energy options.

How to prepare for the game-changer: quantum computers

How should Japanese businesses prepare for these changes? We consider two perspectives: (a) hardware and software manufacturers of quantum computers, and (b) quantum computer users.

From the perspective of manufacturers, based on our research, we envision five types of end-game players (see figure 5):

Figure 5
There are a number of emerging players in the quantum computer software domain



1 Core IP providers
— Provide core intellectual property used by applications, creating unique business models

2 HW/SW integrated key application players
— Control both hardware and software layers, developing end-to-end applications with business models like d-wave

3 Hardware manufacturers
— Focus on production of high-performance quantum computer hardware for a wide variety of applications

4 Quantum computer platformers
— Enable seamless access to various quantum resources through their platform services

5 Emerging research DX domain
— Provide quantum computers in addition to their R&D DX services

Source: Kearney analysis

1. **Players that secure exclusive patents for core technologies in software** and generate revenue through licensing (similar to Qualcomm in the communications industry)
2. **Players that produce and supply both hardware and software for quantum computers**, accumulating data, know-how, and market dominance (like IBM with its PC and Lotus 1-2-3)
3. **Players that provide competitive, versatile quantum computing resources** and dominate the hardware layer (like today's hyperscalers in data centers)

4. **Software platform providers that win by offering modular software** (like Hugging Face, which has become a unicorn by supporting the sharing and execution of AI models)
5. **Players from adjacent fields that are entering the market**, for example, companies specializing in lab automation may leverage their customer base and validation expertise to gain a competitive advantage in automating virtual testing environments using quantum computers (like Mitsubishi Chemical, Shimadzu, and Chugai Pharmaceutical, which are already advancing lab automation initiatives)

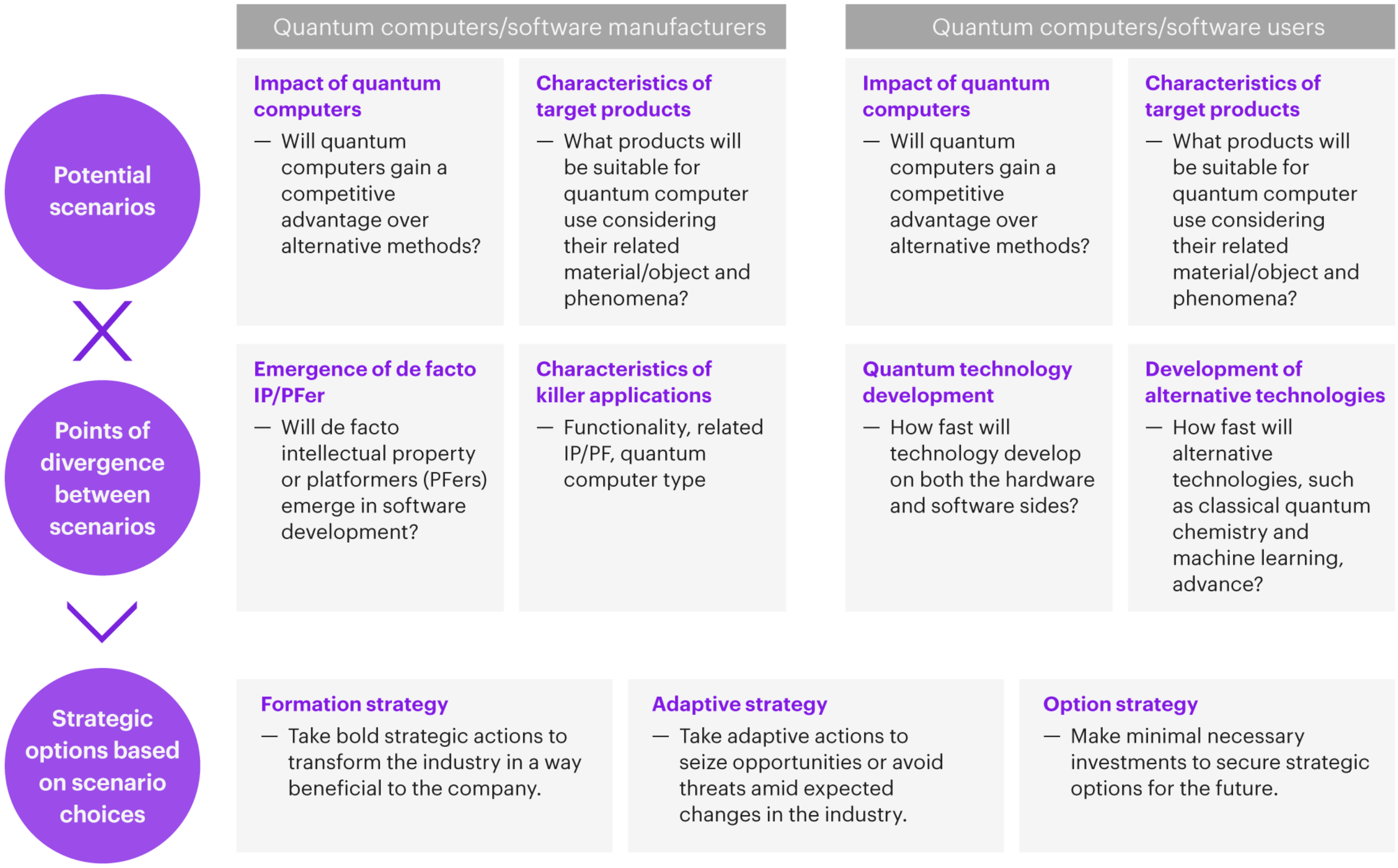
Among these, the first area where winners and losers will emerge is the hardware-agnostic development of software. Core IP (type 1) and platforms (type 4) may already have winning players. The next turning point is the emergence of killer applications, which will drive full-scale market growth. Players that secure these applications or provide hardware suited to them (type 2 and 3) will have growth opportunities. In the long term, adjacent R&D DX players (type 5) may also capture killer applications and drive growth using their wide customer base.

Quantum computer manufacturers (both software and hardware) must envision which of these winning players they aim to become. And software manufacturers, in particular, must consider whether to focus on developing killer applications or establishing core IP, as well as their positioning relative to R&D DX players and platforms in the long term.

From the perspective of users, the key question will be identifying when and how to use quantum computers within their product development process. The timing for quantum computing applications will vary significantly depending on the object or phenomena they are dealing with. For example, quantum computing will be applicable earlier for small molecules than for solids, and even for solids, the timeline will differ depending on whether the material is used as a catalyst or as a light-absorbing material. Therefore, companies must reassess their R&D themes, evaluate the applicability and timing of quantum computing for each product, and integrate these considerations into their overall quantum computing strategy.

In conclusion, quantum computing strategy requires careful scenario analysis to map out potential future scenarios, the implications for each scenario, and the triggers for divergence between them. Companies will need to decide whether to shape the market (formation strategy), quickly adapt to a formed market (adaptation strategy), or secure strategic options with minimal investment (option strategy). Quantum computing has the potential to be a transformative wave, and careful preparation will be crucial for businesses in navigating—and capitalizing on—this rapidly evolving field (see figure 6).

Figure 6
Quantum computing strategy requires careful scenario analysis to map out potential future scenarios



Source: Kearney analysis

Kearney uses accumulated knowledge about quantum computers and our expertise in scenario analysis to broaden and evaluate potential use cases for quantum computers tailored to our clients' contexts, as well as to explore partnerships and formulate quantum computing strategies. We can help develop digitalization strategies for research and development that encompass a broader scope, including materials informatics, and help formulate strategies for nurturing and using players in the quantum computing domain (see figure 7).

Figure 7

Kearney can provide support in a number of areas

1

Strategy for leveraging quantum computers

- What are the current and future development themes for utilizing quantum computers?
- What are the development trends for quantum computers that should be considered? Who are the potential partners?
- Based on the above, how should the company position itself within various scenarios?

2

Digitalization strategy for research and development

- Organize the status of digitalization in your research and development and identify further digitalization initiatives (such as database construction, machine learning, quantum computers).
- Based on the above, define the ideal future state and outline a strategy to achieve it.
- Provide planning and execution support to realize the desired future state.

3

Strategy for nurturing and leveraging players in the quantum computing field

- Organize partnerships with domestic and international quantum computing players.
- Based on the status of each player, outline scenarios for the future of the quantum computing market.
- Based on the above, define how your company, as well as Japan, should approach the quantum computing landscape.

Source: Kearney analysis

Digitalization in R&D within the fields of chemistry and materials is urgent and cannot be delayed. Companies such as Meta are creating chemical databases based on quantum chemistry calculations performed on classical computers, and IBM has announced chemical synthesis devices that combine AI technology and robotics. The technological development by players outside the materials and chemistry sectors is also significant.

Companies must strategize how to navigate this wave of digitalization and the forthcoming major wave of quantum computing sooner rather than later as technologies advance rapidly—as well as consider the significant opportunities presented by the insights in this report.

---

[1] Please note that this report primarily addresses gate-based quantum computers and does not cover quantum annealing computers.

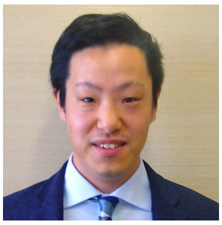
This article is translated from the Japanese version, which you can find here.

This report was based on literature reviews and interviews with various stakeholders. We would like to express our gratitude to all interviewees for their valuable insights.

Authors

Tak Umezawa
Partner

Kakuya Nishikawa
Partner



Yusuku Isaka
Consultant

About Kearney

For 100 years, Kearney has been a leading management consulting firm and trusted partner to three-quarters of the Fortune Global 500 and governments around the world. With a presence across more than 40 countries, our people make us who we are. We work impact first, tackling your toughest challenges with original thinking and a commitment to making change happen together. By your side, we deliver—value, results, impact.

For more information, permission to reprint or translate this work, and all other correspondence, please email insight@kearney.com. A.T. Kearney Korea LLC is a separate and independent legal entity operating under the Kearney name in Korea. A.T. Kearney operates in India as A.T. Kearney Limited (Branch Office), a branch office of A.T. Kearney Limited, a company organized under the laws of England and Wales.