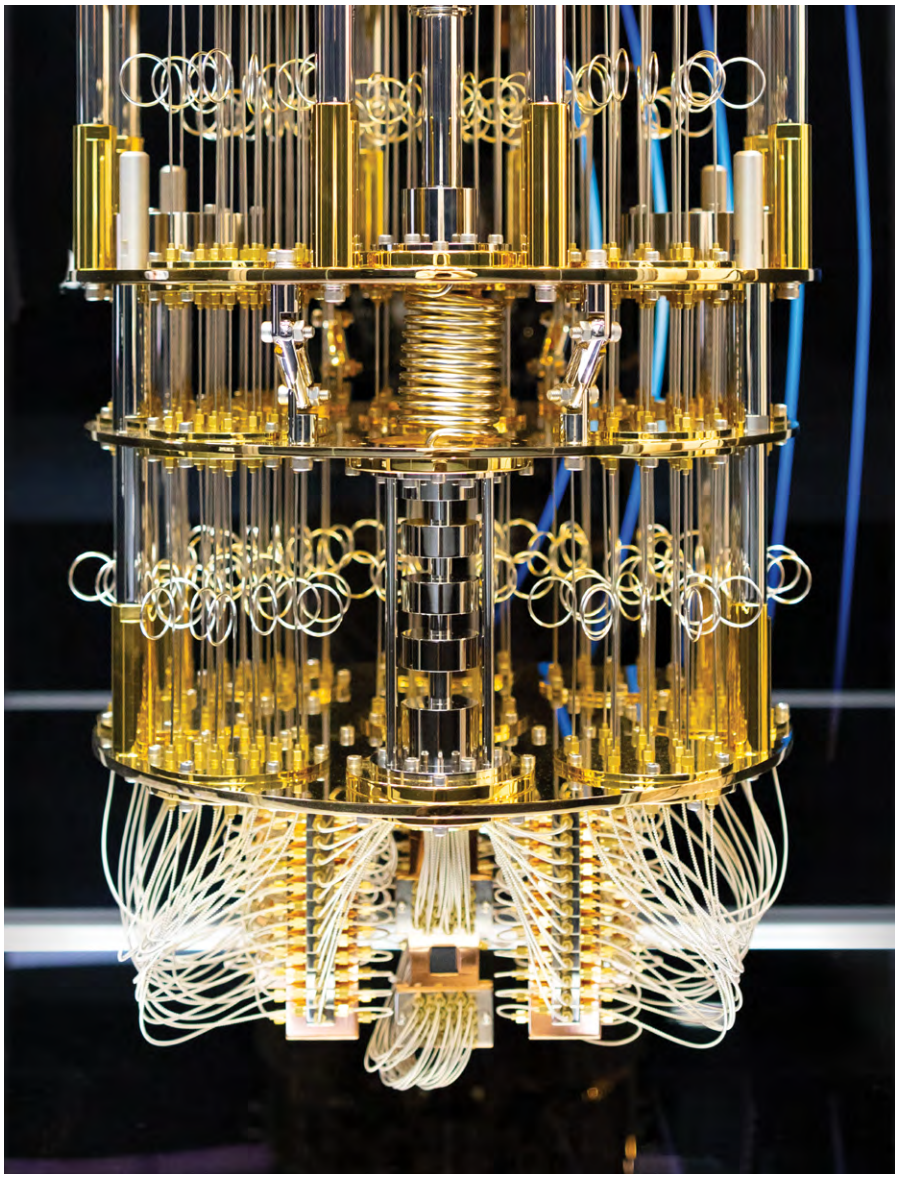


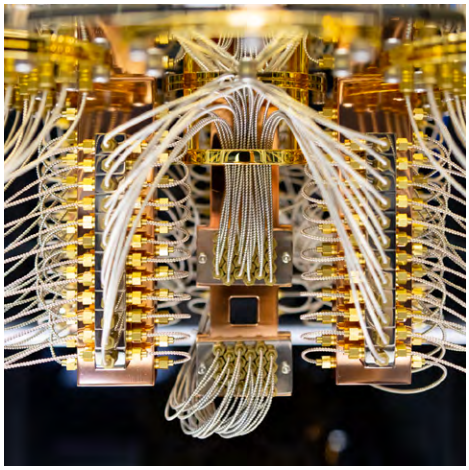
Make quantum readiness real

Driving business utility with ecosystems, innovation, and talent

IBM

How IBM can help

Partnerships in quantum computing between technology providers and visionary organizations are expanding. Their aim is nothing short of developing quantum computing use cases and corresponding applications that solve previously intractable real-world problems. The IBM Quantum Network is a global ecosystem of more than 250 Fortune 500 companies, leading academic institutions, startups, and national research labs, enabled by IBM's quantum computers, scientists, engineers, and consultants. Participants collaborate to accelerate advancements in quantum computing that can produce early commercial applications. Organizations that join the IBM Quantum Network can experiment with how their high-value problems map to a real quantum system. They can access 100+ qubit IBM Quantum processors to explore practical problems important to industries. Visit https://www.ibm.com/quantum for more information.



What do quantum-ready organizations (QROs) have in common?

In 2023, organizations invested 7% of their R&D budget in quantum computing, up 29% from 2021. By 2025, this is expected to further increase by another 25%.

Ecosystem enthusiasts.

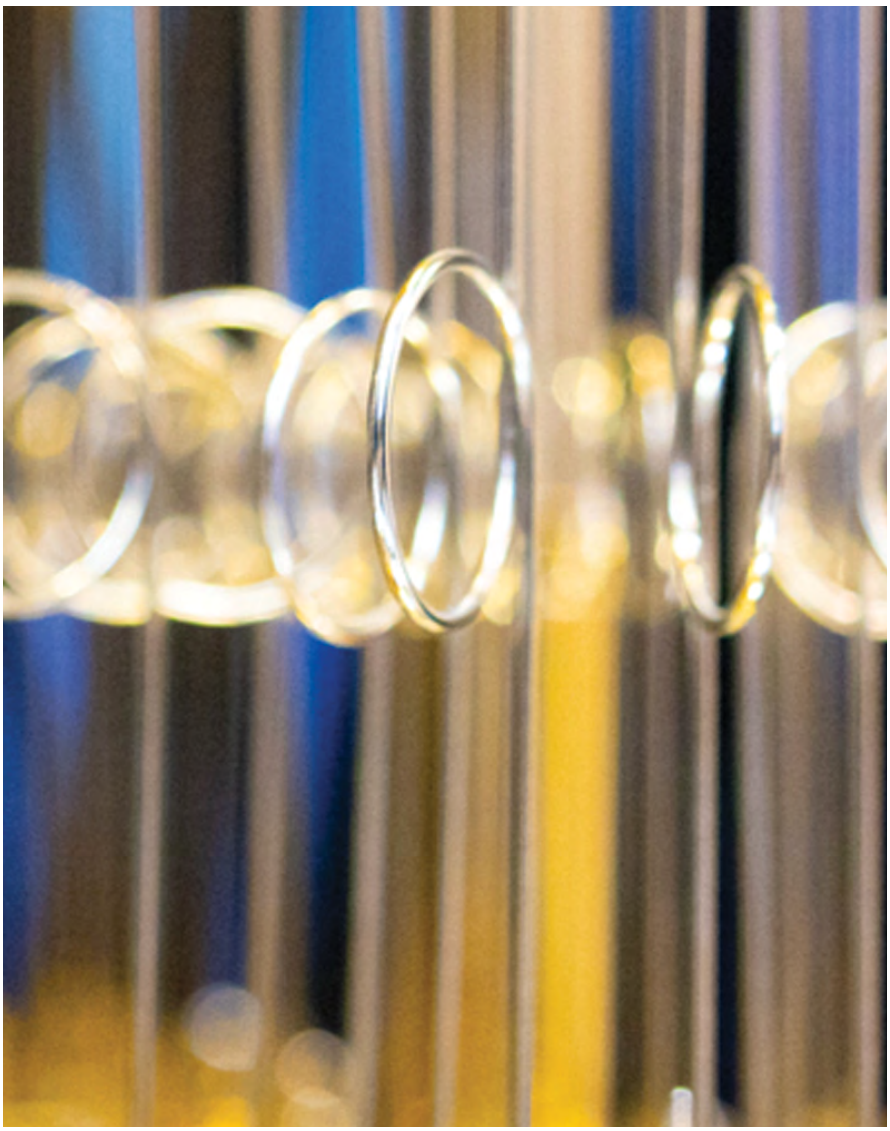
Over 60% of QROs actively engage in quantum ecosystems for use cases, educational programs, or hardware access. In an inadvertent nod to the importance of ecosystems, 93% of organizations at the lowest level of readiness do *not* participate in any quantum ecosystem.

Contagious innovators.

QROs tend to be advanced in other innovative technologies as well. In fact, quantum-ready organizations run 48% more AI workloads than their least-ready counterparts.

Talent nurturers.

QROs have a greater understanding of the skills gap—identified as the top barrier to adopting quantum computing—and are nearly three times more effective in their workforce development approaches. These include developing internal quantum skills, attracting STEM talent, and partnering with academic institutions and research labs.



Preparing for a new era of quantum utility

Until recently, quantum systems were considered "a plaything for theoreticians."[1] But that perspective is now becoming obsolete. Quantum computing is coming of age, recently showing evidence of utility—a point at which quantum systems could serve as computational tools to tackle problems that classical systems may never be able to solve—and astute organizations are getting ready. Leaders who fail to understand and adapt could find themselves far behind their competitors.[2]

By leveraging quantum mechanics, quantum systems can explore problems that have long perplexed classical computers. Many organizations are driven by this potential and are pursuing partnership and investment strategies accordingly.

In 2023, organizations invested 7% of their R&D budget in quantum computing, up 29% from 2021. By 2025, this is expected to further increase by another 25%. Additional research shows the global quantum computing market valued at $866 million in 2023—and it's anticipated to reach $4.375 billion by 2028, a compound annual growth rate (CAGR) of 38.3%.[3]

And here's another call to action: *early adopters are poised to reap the rewards*. Analysts estimate that by 2035, quantum computing technology could potentially create $450 billion to $850 billion in net income for end users via cost savings and revenue generation. The catch, and a critical note at this stage of the game: in most industries, as much as 90% of that value could go to early adopters.[4]

This dynamic quantum computing landscape was the catalyst for our research inquiry: just how ready are organizations today to utilize quantum computing in tangible, actionable ways?

To learn more, the IBM Institute for Business Value (IBM IBV) has developed a Quantum Readiness Index (QRI). This index leverages proprietary, self-reported data from an in-depth survey of C-suite executives representing 565 organizations with annual revenue of $250 million or more. The QRI indicates:

—Where organizations fall along the readiness spectrum
—What characteristics define a quantum-ready organization (QRO) today
—What targeted actions can propel organizations along their quantum journey.

(For more information, see “Perspective: The Quantum Readiness Index” on page 5 and “Research and methodology” on page 28.)

Among the organizations surveyed, we designated those with the highest QRI scores (the top 10%) as QROs. These organizations, although diverse across countries and industries, share many similarities.

In their own right, these are high-performing organizations in their industries: eight in ten QROs outperform their peers globally in efficiency and profitability (see Figure 1). And even though quantum investments are yet to yield a positive ROI, QROs anticipate being nearly five times closer to generating value on these investments than their peers. More than half of that investment (55%) is directed toward research and experimentation (24%), ecosystem participation garners 16%, and workflow redesign nets 15%.

Our research also reflects the impact of preparedness. Today, a QRO is 3.5 times more motivated to accelerate innovation and 2.5 times more driven by obtaining new patents than by an immediate focus on solving an intractable business problem with current quantum computing technology. It’s speculation but certainly logical that accelerated innovation and patents could *lead* to solving intractable business problems in the future. This optimism is why, over the next 10 years, our respondents overall expect the impact of quantum readiness on ROI to increase by over 300%. In other words, these organizations recognize the time to value of quantum computing.

In the sections that follow, we examine three differentiating attributes of quantum-ready organizations. Chapter 1 delves into their engagement with quantum ecosystems. Chapter 2 explores their technology and innovation capabilities as precursors to quantum readiness. Chapter 3 illuminates strategies for closing skill gaps. Along the way, we also share specific case studies of quantum in action, as well as questions to ponder. Finally, we present an action guide to help organizations, whatever their stage of quantum readiness, improve their preparedness.

FIGURE 1

QROs

A prevalence of outperforming

Perspective

The Quantum Readiness Index

The Quantum Readiness Index (QRI) is a weighted average index that tracks the global state of quantum readiness. The QRI evaluates indicators across three dimensions of strategy, operations, and technology. Scores for each indicator are weighted based on our experience with clients. Using this data, we computed a 100-point index. The QRI is designed to be used over time to track changes in readiness of an organization, industry, or region.

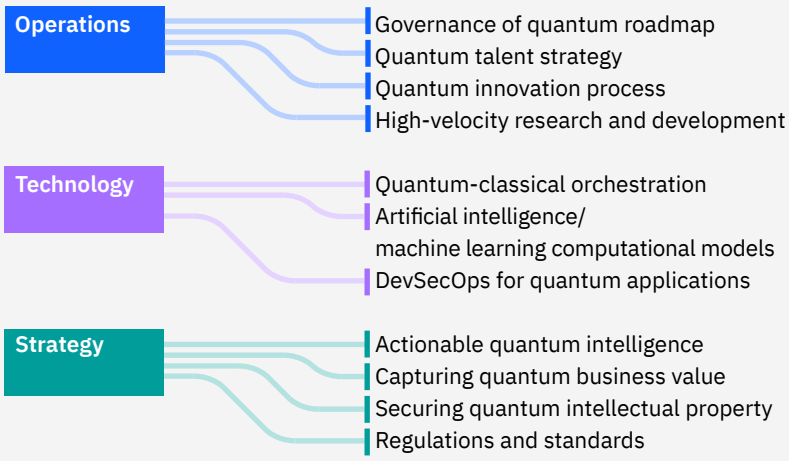
Today, an organization's quantum computing readiness score is most influenced by its operating model: if an organization invests in a team and a process to govern their quantum innovation, they are better positioned than peers that focus just on the technology without corresponding investment in their talent and innovation process.

Yet overall, the Quantum Readiness Index shows low levels of readiness across all industries and regions: 22 on the 100-point index.

As quantum computing rapidly approaches utility, we expect strategy and technology capabilities to play a greater role in an organization's readiness. For more information and a complete depiction of the QRI, see "Research and methodology" on page 28.

The QRI

Comprehensive metrics spanning operations, technology, and strategy



Perspective

What Japan is doing right

When it comes to quantum computing, Japan has a leading formula: in our research, they claimed the highest percentage of QROs, with nearly 20% of organizations meeting our criteria. What's contributing to their success?

Strategic policy

Back in 2020, Japan established a national quantum strategy outlining key technology areas of focus, including quantum computing, quantum simulation, quantum measurement, quantum communication and quantum sensing, quantum cryptography, and the physical properties of quantum technologies and materials.

Not content with abstract ambition, the Japanese government established highly technical, specific plans. These included developing international cooperation; promoting industry innovation in quantum technologies; enhancing the country's intellectual property (IP) system relating to quantum; supporting human resources for quantum; and improving healthcare, with an emphasis on Japan's aging population.[5]

Collaborative research

July 2020 brought the launch of the Quantum Innovation Initiative Consortium, with the University of Tokyo, Keio University, IBM, Toshiba, Hitachi, and several other Japanese companies constituting membership. The consortium enables collaboration between universities and the industry and strives to improve students' skills and expertise in quantum computing. It also promotes quantum business opportunities and R&D activities for quantum computing in Japan.[6]

Continued government funding

More recently, the Japanese government made a commitment to contribute $31.7 million (4.2 billion yen) toward the development of a shared, cloud-based quantum computing platform. The Ministry of Economy, Trade, and Industry (METI) will distribute the funding to a quantum computing collective led by the University of Tokyo over the next five years. Currently, the university uses an IBM Quantum system with the company's 127-qubit Eagle processor.[7]

Breakthroughs and partnerships

One significant partnership example is the May 2023 announcement of a 10-year, $100 million initiative with the University of Tokyo, the University of Chicago, and IBM to develop a quantum-centric supercomputer powered by 100,000 qubits. This 100,000-qubit system would serve as a foundation for tackling challenges that even today's most advanced supercomputers may never be able to solve.[8]

As well, in October 2023, IT services provider Fujitsu and the scientific institute RIKEN announced the development of a new 64-qubit superconducting quantum system at the RIKEN RQC-Fujitsu Collaboration Center. The new quantum system builds on the technology developed by RIKEN and a consortium of joint research partners, including Fujitsu, for Japan's first superconducting quantum system, which was revealed to the public in March 2023.

Fujitsu and RIKEN also announced a platform for hybrid quantum computing, which combines the computing power of the newly developed 64-qubit superconducting quantum system with one of the world's largest 40-qubit quantum system simulators, developed by Fujitsu.[9]

With respect to partnerships in general, Dr. Akihisa Sekiguchi, Corporate Fellow of Tokyo Electron Limited (TEL), observes: "Whether with supercomputers, servers, cloud, simulation-related computing resources or part of a hybrid cloud solution, the assumption is that services will be provided seamlessly. *But you need to partner with the right universities and organizations.*"

Quantum-enabled cell-centric therapeutics

Pioneering new research in healthcare and life sciences[10]

In our research, healthcare and life sciences (HCLS) is the industry sector with the highest concentration of QROs at 18%. Here's how the HCLS sector is setting itself apart:

Working groups

Working groups can bring together the best industry pioneers and scientists to accelerate effective utilization of quantum computing.

One such HCLS working group was established by IBM Quantum with Cleveland Clinic, the University of Chicago, and the University of Toronto. This group is investigating quantum algorithms, which use a significantly different computing paradigm that could potentially represent biological data—and learn from it—more efficiently. This could enable researchers to explore new frontiers for biological research and facilitate biomedical discoveries.

R&D innovation

Therapeutic design and discovery have traditionally focused on drug-target identification and interaction optimization. While quantum algorithms exist, researchers have typically taken classical approaches. It's a strategy that has led to the approval of many novel therapeutics (for example, small molecule inhibitors, chemotherapeutic, and antibody therapies) across a multitude of diseases.

However, since the 1950s, research and development costs per new approved drug have been doubling every nine years.[11] For many diseases, effective therapies remain elusive. In fact, target-centric approaches may be reaching the point of diminishing returns.

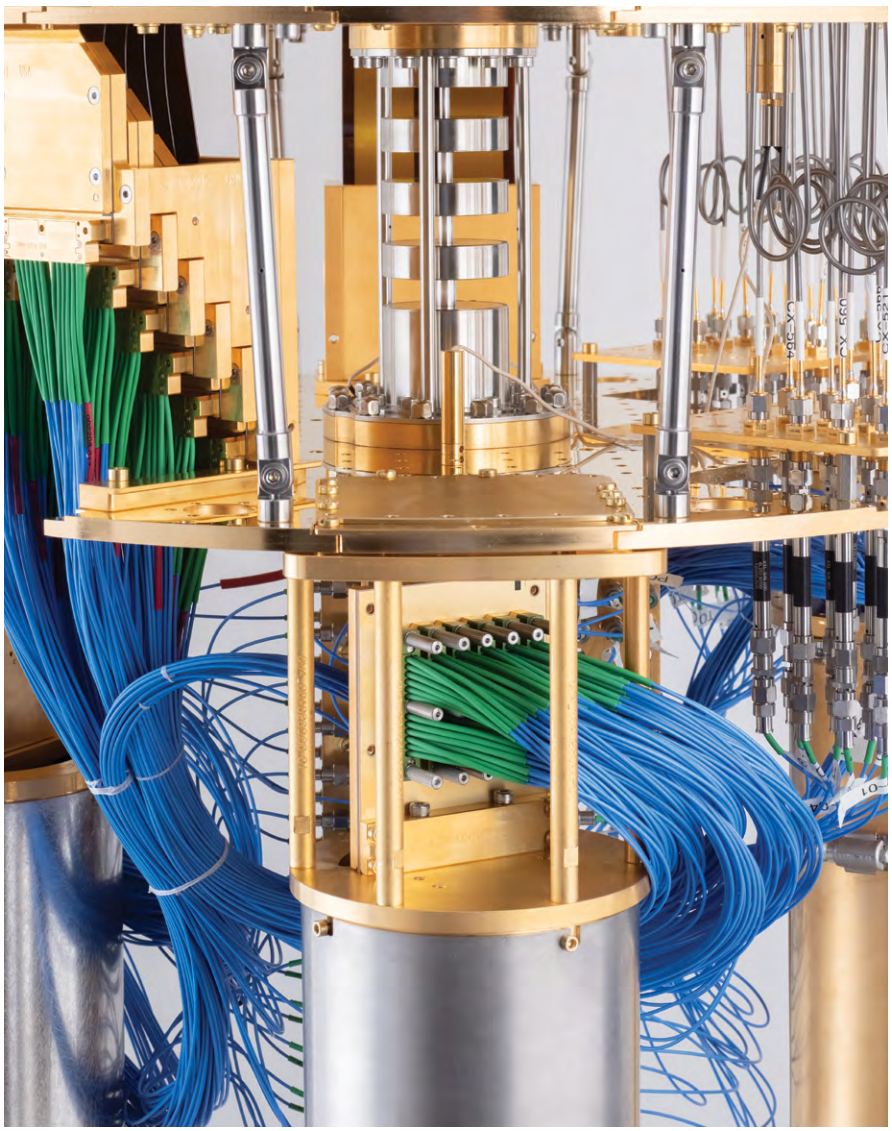
But there's hope. Researchers are making significant progress with quantum-enabled cell-centric therapeutics. Spatiotemporal single-cell, cell-line, imaging, drug profile, and clinical data are analyzed with four quantum computing technologies that can capture varying aspects of cellular behavior.

Insight integration

Insights from each research area can be valuable in and of themselves, and they can also be combined in various ways that can empower researchers to provide new treatment options that optimize the cellular context and improve therapeutic response.

For example, by developing a comprehensive understanding of how cancer cells behave—and modeling that behavior both individually and in aggregate—treatment plans can emerge. These new treatments could potentially be developed to manipulate a cancer and its tumor microenvironment into a more therapeutically responsive state. Or treatment could shift the tumor into an indolent phase that transforms the disease into a more manageable, chronic condition.

Quantum computing may serve as an enabler in this cell-centric approach to therapeutic design. This illustrates just one example of how working groups can significantly contribute to advancing quantum computing applications across several domains.



Chapter 1

Strength in numbers: Engaging ecosystems and quantum service providers

Quantum-intrigued organizations might aspire to quantum readiness, but without extensive quantum know-how on staff, they might not know how to start—or progress. Or, even if they're quantum ready, the speed at which quantum computing evolves makes it challenging for organizations to keep up.

This is where ecosystems come into play. Quantum computing ecosystems—with opportunities for collaborative innovation—are fast becoming fertile ground for training users in quantum computing applications to real problems.[12] For example, the IBM Quantum Network is a worldwide collective—a community of over 210 Fortune 500 companies, academic institutions, startups, and national research labs working with IBM to advance quantum computing.[13]

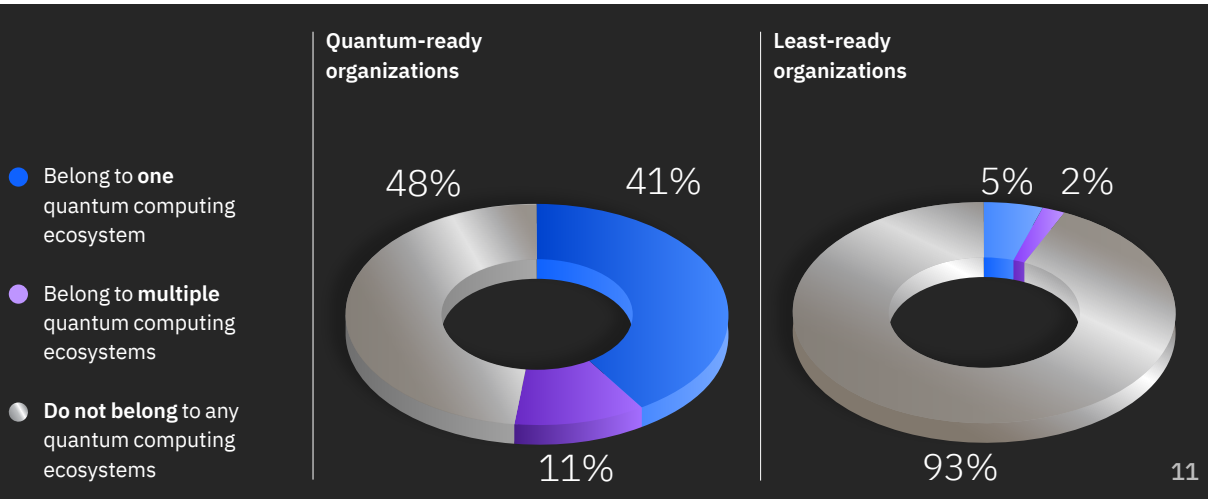
In our survey, over half of QROs reported belonging to a quantum computing ecosystem, with 11% belonging to multiple ecosystems (see Figure 2). And, in an inadvertent nod to the importance of ecosystems, 93% of organizations at the lowest levels of readiness do not participate in any quantum ecosystem.

Quantum ecosystems can serve as a platform for efficiency for QRO quantum programs, with these organizations reporting they're nearly five times closer to business value than other respondents.

FIGURE 2

Foundational to QROs

Higher ecosystem engagement



What defines an effective quantum ecosystem?

The most common impetus for participating in quantum ecosystems? Use cases, with seven out of ten QROs citing them as the primary motivation. Algebraic problems have the highest use case activity, with 63% of QROs experimenting in this area. Simulation is the most heavily funded use case area for QROs at 38%.

Two out of three QROs seek out ecosystems to access educational programs, and almost two out of three to access hardware. "One success factor to applying quantum computing is to validate theoretically tested algorithms on physical hardware. This is the only way to get a realistic view of the performance of the algorithms on real hardware at an early stage and make the necessary further developments—both on the software and the hardware side," says Dr. Thomas Eckl, Chief Expert, Computational Materials Design, Robert Bosch GmbH.

Funding can be another benefit, with respondents saying ecosystem and technology partners provide 25% of quantum computing funding for their organizations.

Points to ponder

— What is your current understanding of quantum use cases for your industry?
— Has your organization evaluated potential industry evolution scenarios triggered by quantum computing?
— Does your market intelligence provide insight into quantum trends and competitive intelligence?

When joining or creating an ecosystem, one essential criterion is the optimal mix of external resources versus in-house capabilities. To improve technology and workflows, ecosystem participants need experience and professionals that are relevant to an organization's business and industry problems. Examples include:[14]

1. A quantum service provider organization that offers:
   - Easy access to cloud-based quantum computing systems
   - An open-source programming framework
   - Educational resources such as tutorials and research papers
   - Quantum computing researchers
   - Quantum computing consultants with industry domain and technical expertise
   - Technical support
   - A collaborative community actively engaged in addressing quantum computing challenges.

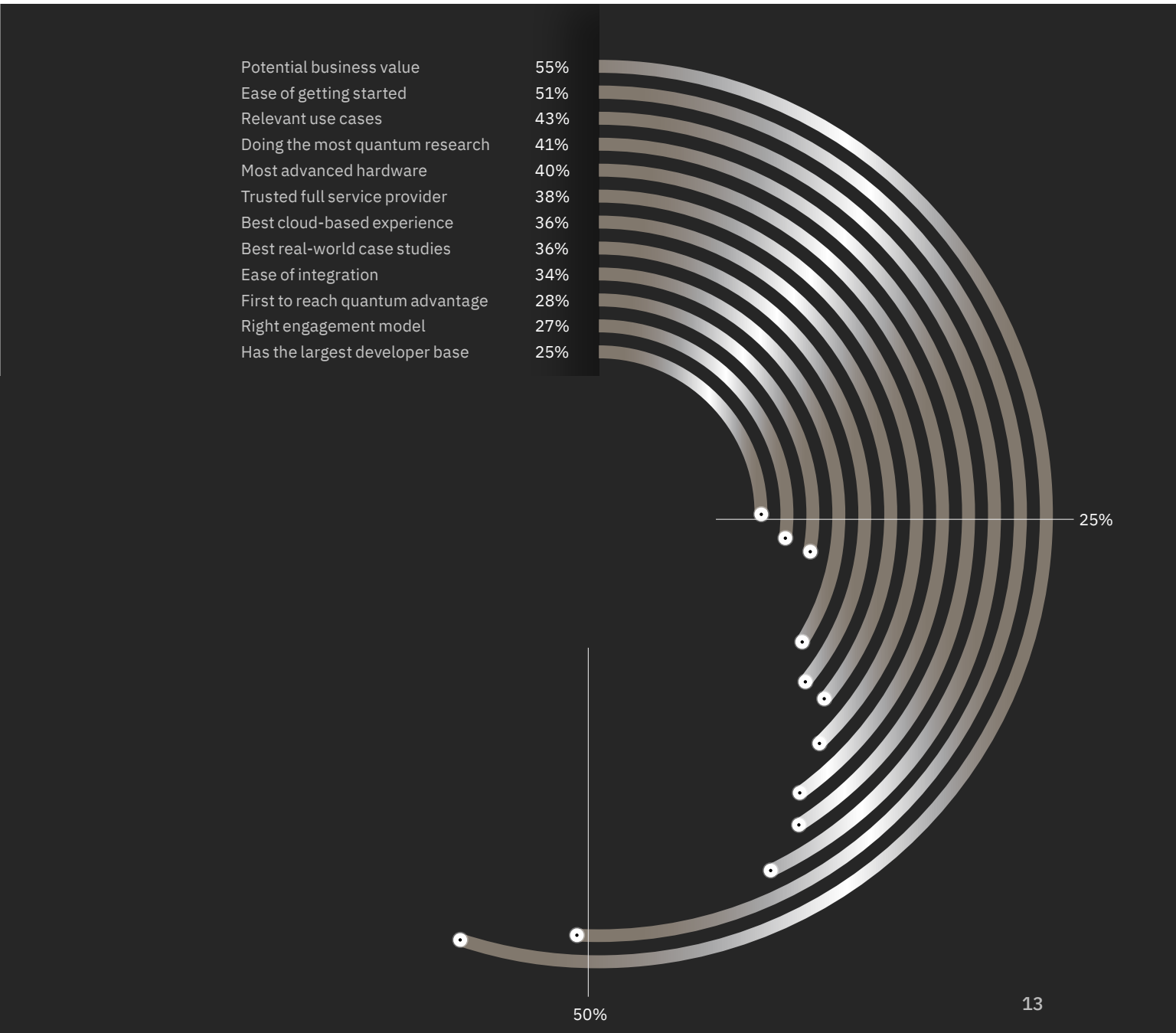
When it comes to engaging quantum service providers, our survey respondents most value understanding business value and ease of getting started, while advanced quantum research and hardware are also important (see Figure 3).

Dr. Giorgio Cortiana, Head of Data, Analytics, and IoT—Energy Intelligence, E.ON, notes his organization's involvement in the European Quantum Industry Consortium, which seeks to boost the European quantum-technology industry's economic growth and competitiveness and enhance value creation across the continent.[15]

FIGURE 3

An ecosystem wish list

What organizations are looking for in quantum providers



2. Quantum computing developers who understand quantum computing application development using open-source code and access to application development libraries and have access to real quantum computing hardware. “Look for a provider who can provide the complete picture,” advises Dr. Akihisa Sekiguchi of TEL. “And keep in mind that programming right now is very hardware-dependent. In five years, it will be automated.”

3. Academic partners and universities conducting relevant quantum computing research and developing budding quantum computing experts that could ultimately be hired.

   E.ON also partners with university students, who can generate master theses on specific quantum computing use cases. “We engage in obtaining public grants, and we clearly have a close collaboration with IBM to help upskill our team,” Dr. Cortiana says.

“Look for a provider who can provide the complete picture, and keep in mind that programming right now is very hardware-dependent. In five years, it will be automated.”

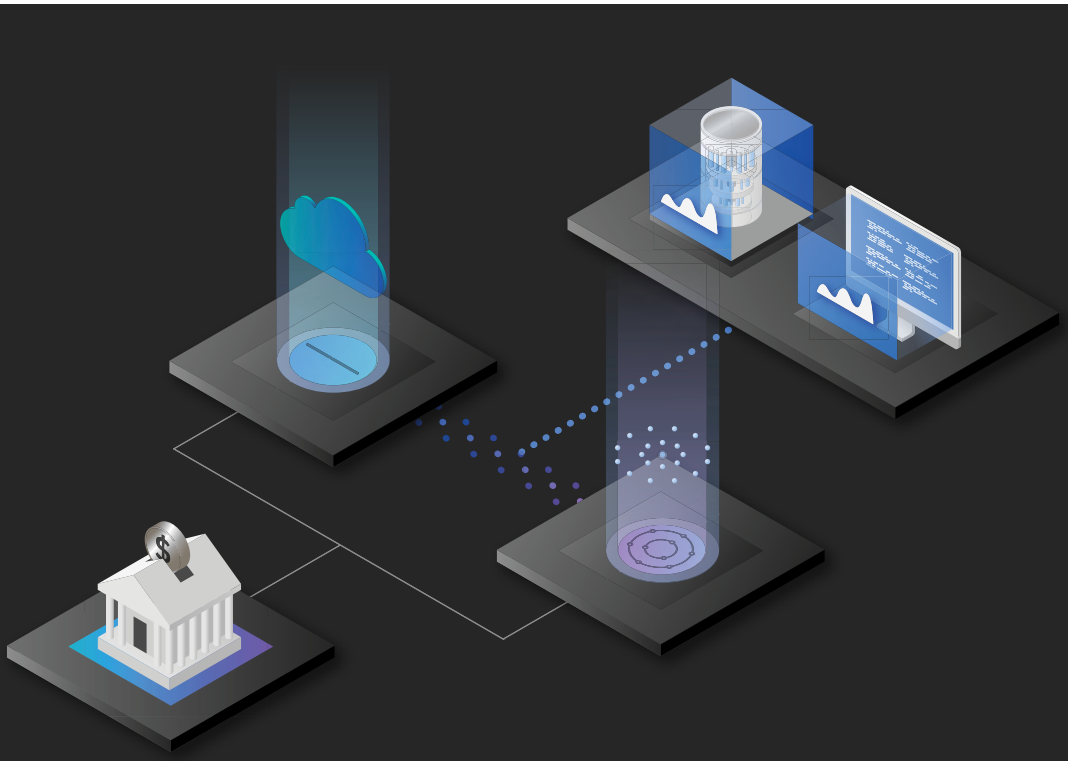
Dr. Akihisa Sekiguchi
Corporate Fellow
Tokyo Electron Limited (TEL)

Chapter 2

The quantum-ready journey: Building on a core of technological innovation

Much of quantum computing technology confounds conventional common sense. For example, in classical computing, bits are either a 0 or a 1. But in quantum computing, quantum bits, or qubits, can be in an infinite number of states all at the same time.[16]

Nonetheless, the process of quantum readiness itself has a linear progression. Nothing can start without funding. Funds can't be productively used without skills (more on that in the next chapter). Funding and skills create innovation, and organizations need actual, quantifiable innovation to align with business strategy. For starters, let's investigate funding.



On your mark, get set, fund

Seekers of funding for quantum computing programs face one obvious challenge. "We know pretty well for which problems quantum computing can become useful," summarizes Dr. Thomas Eckl from Bosch Research. "But we cannot exactly estimate how long it will take until quantum computing will contribute to their solutions, since it [quantum] needs further developments on the software as well as on the hardware side."

Yet the potential of quantum computing is compelling and increasingly demonstrable.[17] Investors—both internal and external to organizations—are responding. Our research shows that across our respondents, organizations are spending a median of $3.6 million annually on quantum computing, with investments steadily increasing.

Where do organizations unearth this funding? Internal investments are the leading source (31%), followed by ecosystem and technology partners (25%). Venture capital funding (23%) and government funding (21%) round out the picture (see Figure 4). As quantum computing and business strategies increasingly synchronize, organizations could have more profound data to support their internal pitches for funding.

"Such a long-term project requires strong internal management support," notes Dr. Eckl. "This is precisely the case at Bosch, as the Bosch management values the potential of quantum computing and strategically supports the research and development of this key technology."

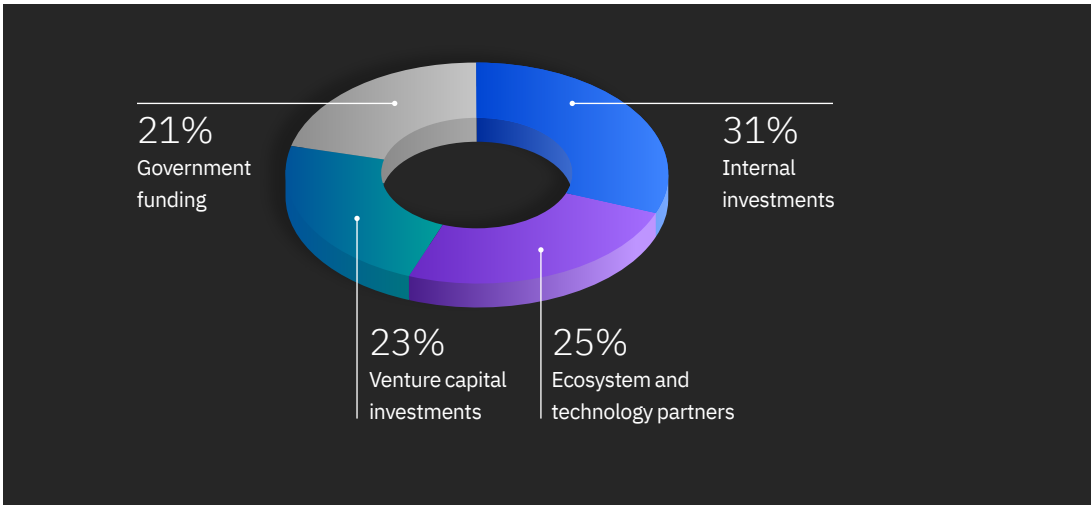
Points to ponder

—Do you have the necessary executive sponsorship for quantum innovation in your organization?
— What is the process entailed in obtaining funding and resources to quantum projects?
— How does your organization manage investments in higher-risk, longer-term initiatives with uncertain business value?
—What are your strategic priorities and how does quantum fit in?

FIGURE 4

The quantum funding quest

Internal investments lead the way



AI and the cloud: Where QROs percolate and innovate

Given the cutting-edge nature of quantum computing, it's reasonable to categorize QROs as highly agile technology innovators overall, and our research confirms that. We found that nine in ten QROs report outperformance compared to their peers in agility, and seven in ten QROs report outperformance compared to their peers in innovation (see Figure 5).

QROs are innovating on AI, running 48% more AI workloads in production than their least-ready counterparts. As well, cloud investments from the start of the decade continue to have a high impact on their quantum readiness—and QROs run 28% of their workloads today on hybrid cloud.

Cloud-based workloads can lay the groundwork for organizations to engage with cloud-based quantum service providers. For example, open-source cloud quantum computing ecosystems provide access to quantum computing on a manageable scale, providing a low-commitment "laboratory" for experimenting with classical versus quantum computing.

For quantum computing to effectively augment classical functions, classical and quantum computing usage should be choreographed—a process that involves evaluating sub-workflows best suited to quantum computing acceleration.

"Our internal position is a hybrid approach, not pure quantum," says Dr. Wade Davis, Vice President of Computational Science at Moderna. "For some problems, it might be ten components classical and one component quantum, or vice versa. That type of alignment is what needs to be done."

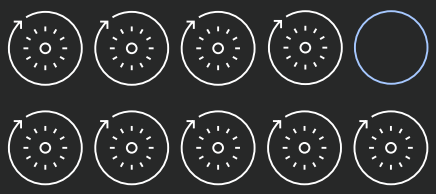
Points to ponder

— How have you identified components of your AI-driven workflow(s) that are quantum-addressable?
— How quickly can business workflows be modified to accommodate quantum enhancement, based on their modularity?
— What key workflows run in a public cloud versus a private cloud versus a hybrid cloud?

FIGURE 5

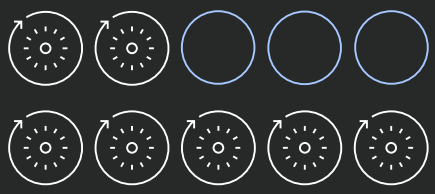
QROs outshine their peers globally

They lead the way in agility and innovation



9 in 10

QROs outperform their peers in **agility**



7 in 10

QROs outperform their peers in **innovation**

It's a process: Aligning quantum computing and business strategy

The point of exploring quantum computing—and all innovation—is to advance an enterprise's business strategy. In effect, the C-suite ultimately expects innovation and experimentation to pay off, even if it's over the long haul.

Yet our research reveals a daunting finding: executives report only 28% alignment of quantum strategy with business strategy. Even organizations with strong executive support and a clear quantum vision report low levels of alignment. However, given that organizations say it will take 13 years to fully integrate quantum computing into their business, perhaps this disconnect is not so surprising. In short, the business must catch up to the technology—and that could require radical thinking.

"In 10 years, we will have a different world," Dr. Akihisa Sekiguchi of TEL anticipates. "Consider the combination of AI and more error-resistant quantum computing. We need to turn the next generation of minds into thinkers, not just observers of patterns."

Dr. Giorgio Cortiana of E.ON elaborates on the value of creativity: "Know your business today and envision what it will be five to ten years from now. Spend time with the business side on key applications and how they could be in danger if we stayed with strictly classical resources. Play with their imagination. This is an opportunity to create new business models."

But even as QROs flourish in ecosystems, lead their peers in adopting ground-breaking technology, and progress with aligning quantum computing and business strategies, success in these areas rests on a critical foundation—and if this foundation is shaky, the soundest quantum computing strategy crumbles. What does the future of quantum computing depend upon most? Skills. And this area warrants a chapter all its own.

Points to ponder

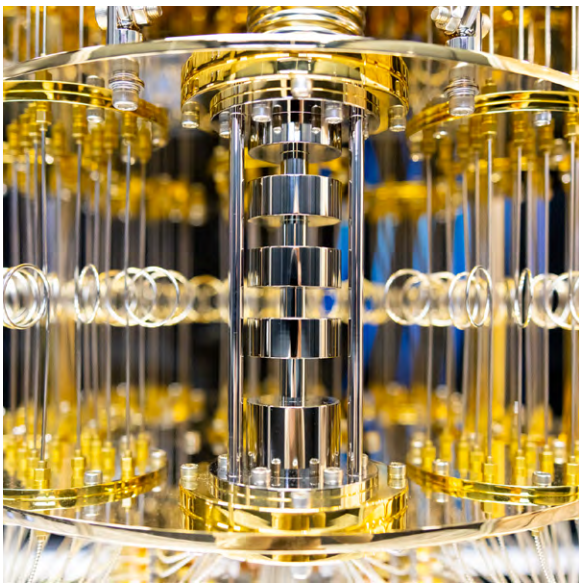
— How do you generate innovation initiatives in support of your quantum computing strategy?
— What amount of future growth and profitability is expected to be driven by quantum-addressable opportunities/capabilities?
— How do you prioritize investments in risky projects?
— How will quantum capability and value generation grow within your organization—through build or buy?

Chapter 3

The elephant in the room: Closing the skills gap

A startling statistic: analysts predict that by 2025, less than 50% of quantum jobs will be filled, unless talent pools significantly expand, or quantum job creation slows.[18] The latter seems unlikely.

According to the World Economic Forum, quantum computing startups have sprouted on every continent, and the number is growing. And, more than half of quantum companies are hiring.[19]



"It's too late to start in three years. Talents and know-how will be short, and we cannot jump on a running train."

Dr. Giorgio Cortiana
Head of Data, Analytics, and IoT—Energy Intelligence
E.ON

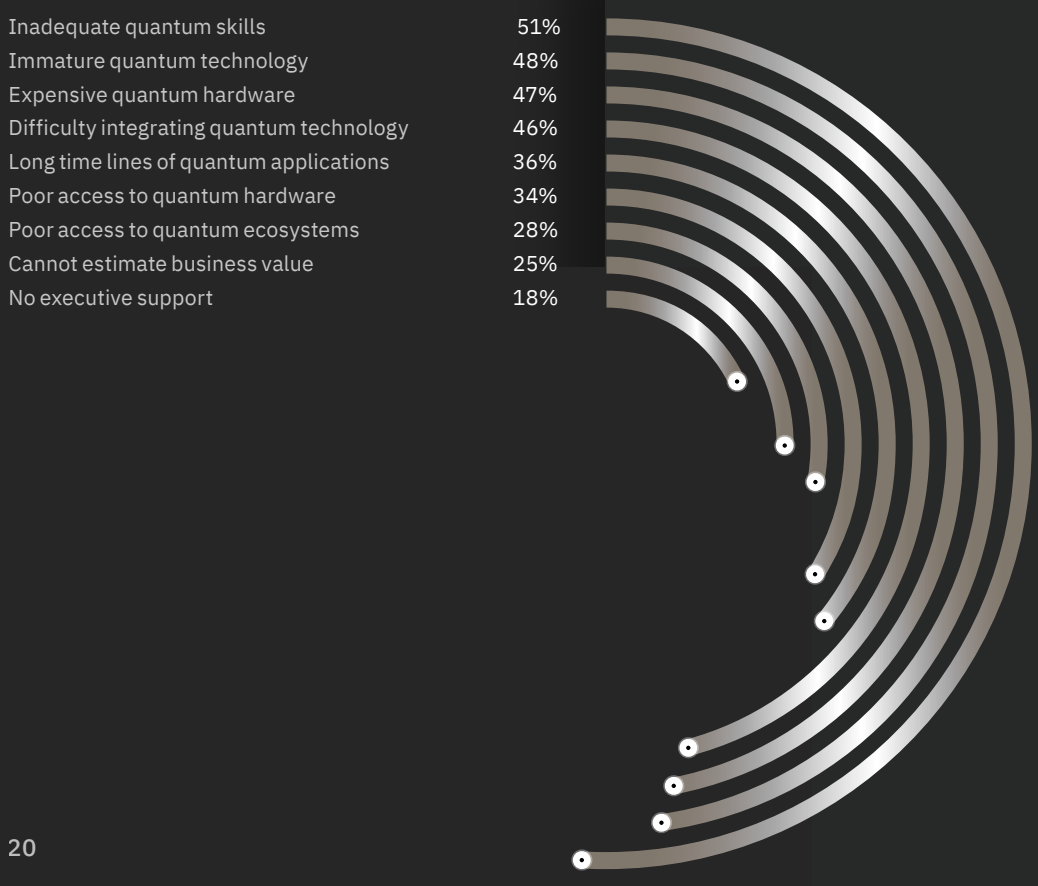
Our own research verifies this dilemma, with respondents citing inadequate skills as the top barrier to adopting quantum computing technology (see Figure 6). Advanced mathematics (84%), quantum physics and chemistry (72%), and quantum algorithms (70%) are the top areas in which they're feeling the pinch across industries.

In fact, across all organizations in our study, 23% of the technology workforce is expected to reskill over the next three years to gain quantum-related expertise. To facilitate reskilling efforts, IBM started Qiskit, a community that builds the necessary code development tools and libraries for quantum developers. Qiskit also offers skills development for thousands of quantum students. Over two billion quantum circuits are run per day over IBM Quantum Services using real quantum systems.[20]

FIGURE 6

Overcoming challenges

Surmountable barriers to adopting quantum computing



How QROs are narrowing the skills gap

Navigating—and ultimately closing—the quantum computing skills gap could create star organizations that shine in the quantum realm, elevated far above those struggling and scraping to attract talent. QROs are demonstrating this already: they have a greater understanding of the skills gap and are nearly three times more effective in their workforce skills and talent development approaches.

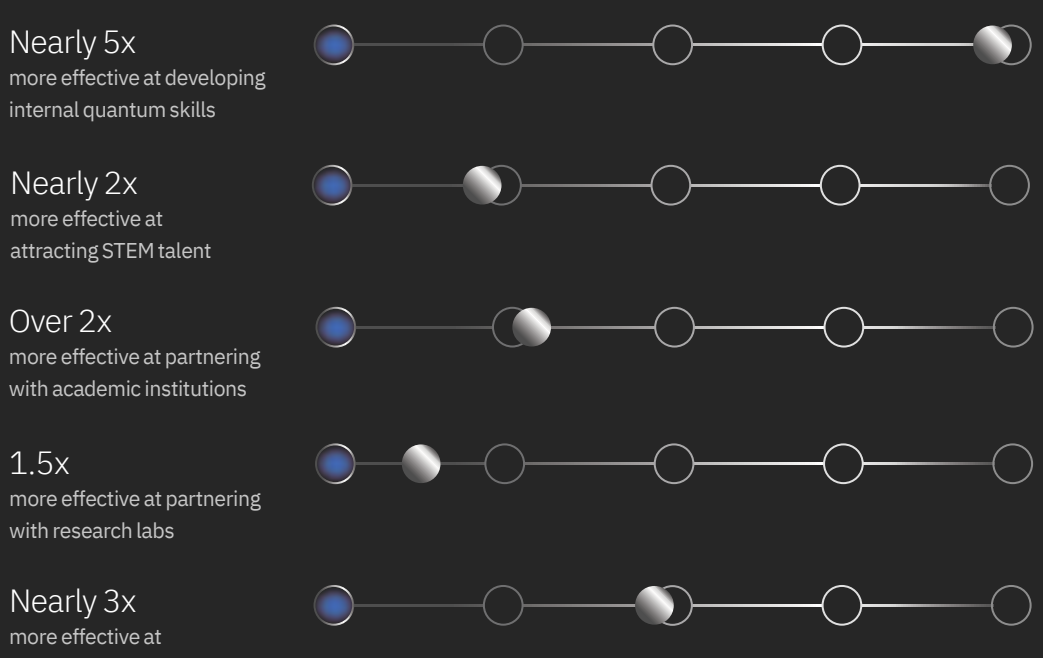
For example, compared to the least-ready organizations, QROs are five times more likely to be effective at developing internal quantum skills. QROs are also twice as likely to be effective at attracting STEM talent, partnering with academic institutions and research labs. And they're three times more likely than the least-ready organizations to be effective at internship programs (see Figure 7 and case study, "The IBM Quantum internship program").

Time is of the essence, warns Dr. Giorgio Cortiana of E.ON. "Organizations need to work on the IP generation side of things, building expertise. It's too late to start in three years. Talents and know-how will be short, and we cannot jump on a running train."

FIGURE 7

Side by side

Key talent differentiators of QROs



Case study

The IBM Quantum internship program: Cultivating quantum computing talent[21]

Since 2020, IBM Quantum has directly trained more than 400 interns at all levels of higher education. Internships with IBM Quantum prepare students with the skills, networks, and career paths needed to launch their careers in the field of quantum computing. In fact, many of these interns have gone on to work at IBM Quantum or elsewhere in the field of quantum after graduation.

Summer internships with IBM Quantum are especially rewarding and include internships based on software developer, hardware engineer, and computational scientist roles. IBM Quantum interns make meaningful contributions to the IBM Quantum Development Roadmap, in effect progressing the field of quantum computing. And every intern works closely with a mentor throughout the summer.

In previous years, IBM Quantum internships have included the Qiskit Global Summer School, poster sessions, and a fireside chat with IBM Fellow and Vice President of IBM Quantum, Jay Gambetta, hosted and organized by IBM Quantum interns.

Arian Noori, a University of Wisconsin graduate student and quantum hardware engineering intern who worked on optimizing cryogenic qubit control transmission lines for improved signal delivery to a quantum chip, said about his experience interning at IBM Research:

“I was surrounded by some of the most intellectual individuals in the world, and everyone was delighted to share insights into their projects. This exposure allowed me to better conceptualize the entire quantum computing ecosystem, enabling a deeper understanding of the most pressing challenges in the field.”

Building community and creativity through quantum literacy

When you're hiring for quantum computing, what's the optimal talent? First, organizations seek candidates who are quantum "aware." This encompasses a broad understanding of quantum computing concepts and the ability to discuss and apply those concepts—what we call quantum literacy. Prospects don't necessarily need an in-depth knowledge of equations and theory.[22]

Our IBM experts point out that this quantum literacy can often be a re-skill, a case of learning enough quantum computing to augment domain expertise and figure out how to integrate quantum computing in that area. Team members don't need PhD-level quantum computing expertise, but they do need enough quantum computing literacy to assess quantum computing capabilities against industry and organizational needs.[23]

"In order to be effective, [a candidate] has to have good solid fundamentals in engineering and sciences but also previous experience in the classical version of AI, machine learning, and so forth," says Dr. Akihisa Sekiguchi of TEL. "Otherwise it's very hard to become literate or proficient in the field."

From there, these resources can form small teams to start identifying problems—whether industry-changing breakthroughs or workflow accelerators—in which quantum computing can play a role. Start by developing and testing large-scale prototypes of hybrid workflows to gain a better understanding of implications to the business and systems maturity, capitalizing on opportunities for learning, growth, and innovative thinking.

Team members don't always need PhD-level quantum computing expertise, but they do need enough quantum computing literacy to assess quantum computing capabilities against industry and organizational needs.

The scarcity of hands-on skills

Second, candidates who have hands-on lab skills are favored over those with none.[24] "We want people who can come in and start working with quantum applications," notes Dr. Wade Davis of Moderna. Yet in a 2021 interview, one IBM industry expert estimated only 3,000 skilled quantum workers existed, and that base needed to double or triple.[25]

Acquiring this level of deeply technical skill can be challenging, especially when competing against universities, startups, and vendors. "Everyone wants a quantum scientist," says Dr. Sekiguchi of TEL. This "talent drought" can boost the appeal of up-and-running ecosystems with their own talented quantum teams.

"Sometimes [candidates] might have experience in quantum physics or chemistry—but not quantum computing," Dr. Davis adds. "They have experience with quantum, but not the right experience."

"Sometimes [candidates] might have experience in quantum physics or chemistry—but not quantum computing. They have experience with quantum, but not the right experience."

Dr. Wade Davis
Vice President of Computational Science
Moderna

The end game: From quantum-literate to quantum-agnostic

One irony: we talk about the need for quantum literacy, quantum awareness, and of course, hands-on quantum computing skills. These are ongoing, valid concerns. But ultimately, the technology will be, at least to the end user, agnostic.

"People will use a tool to solve problems, and they won't care about which part is based on quantum technologies and which part is based on classical computing," predicts Dr. Eckl from Bosch Research. "It is the workflow designers who bring those components together, under the hood, to the point where the end user is not even aware of the quantum dimension."

To achieve that seamless environment both for individual users and across organizations, quantum technology and all its manifold benefits depend on a meticulously constructed foundation of skills.

And those skills remain the biggest challenge to quantum readiness.

Points to ponder

— What portion of quantum and AI skills can be acquired, developed, or accessed through collaboration and re-skilling?
— What is your talent strategy to support the integration of early prototypes of quantum and classical hybrid workflows?
— Have multiple roles been defined for integration of quantum solutions versus designing new applications?
— Is there a plan to continuously develop quantum and AI skills to help ensure the organization is keeping up with progress in these fields?

"People will use a tool to solve problems, and they won't care about which part is based on quantum technologies and which part is based on classical computing."

Dr. Thomas Eckl
Chief Expert, Computational Materials Design
Robert Bosch GmbH

Accelerating business utility with quantum

Whether you are just starting your quantum explorations or if you've already progressed to experimenting with qubits and more, you will find impact in our action guide below. These steps can help organizations close gaps in readiness. Even QROs can further accelerate their preparedness for business utility by continuing to refine their strategy, optimize their operations, and further their technology capabilities.

01

Operations

- *Evaluate your innovation roadmap.* Create an innovation process that provides funding for emerging technologies. Consider what portion of your research and development budget is allocated to quantum computing.
- *Develop a talent strategy—and follow it.* Cultivate quantum-literate employees and managers. Enhance the skill sets of current employees and establish a concrete tactical approach to recruit quantum-related expertise to your organization or ecosystem.
- *Continue to build quantum fluency.* Engage technical teams in learning experiences with hands-on applications of quantum algorithms through continuous, guided prototyping. The more quantum-ready and highly trained your current staff is, the greater your attractiveness to potential recruits.
- *Build or join an ecosystem.* Engage actively with quantum ecosystems, industry working groups, government initiatives, and universities. Consider an organization's track record, engagement model, and roadmap as criteria for a successful partnership.

  "It takes quite a long time to create the relationships and ecosystem," says Dr. Giorgio Cortiana of E.ON. "The space is too big for only one industry to drive it. Synergy and collaboration should be fostered to be successful."
- *Share responsibility.* Integrate quantum adoption roadmaps into the innovation agenda and create shared responsibility across business and technical executives.
- *Invest in agile innovation.* Examine your workflows to accelerate R&D, starting from ideation through integration. Encourage and reward risk in innovation.

02

Strategy

- *Stay up to speed on how quantum computing could impact your business.* Monitor ongoing developments and build quantum computing into your market intelligence function to follow the potential evolution of your industry triggered by quantum computing innovations. (If you haven't read *The Quantum Decade*, published by the IBM IBV, it is a great starting point).
- *Figure out what's holding you back.* Determine your industry's intractable barriers. Build hypotheses to identify use cases where quantum technology can address these previously unsolvable problems and open new ways of conducting business.
- *Get your tech leaders and business executives talking—to each other.* Executives report only 28% alignment of quantum strategy with business strategy. To align business leaders to your quantum vision, demonstrate that quantum investments are high risk but high benefit in the long term.
- *Prepare for the long horizon.* Recognize the time to value on quantum computing and position investments and risk and value expectations accordingly.

03

Technology

- *Embrace advanced classical computing technologies.* The combination of AI, hybrid cloud, and other advanced computational models can ultimately help support quantum computing-addressable workflows.
- *Take your quantum aspirations to the cloud.* Build a hybrid cloud architecture that enables orchestration and interoperation of quantum-classical workloads. Determine which workflow subsections are best suited for quantum computing.
- *Forget the "all or nothing" approach.* Experiment with the duality of quantum/classical computing combinations. Understand the classical capabilities needed to harness quantum, and how quantum and classical approaches both differ and complement each other.
- *Find your technical gaps—and fill them.* Experiment with applications of existing quantum algorithms to your selected use cases. Create a collaborative model for evolving your vision and testing hypotheses.
- *Experiment and iterate—repeatedly.* Engage in agile practices that result in high velocity of research and development and iterative solution design. Create a DevSecOps framework to build, test, deploy, and update quantum computing applications. Continuously refine your strategy and experiments.

Research and methodology

In conjunction with Oxford Economics, the IBM Institute for Business Value interviewed 565 CxOs with primary responsibility for technology and innovation strategy. Of these, over 100 executives had primary responsibility for their organization's quantum computing strategy.

We selected 15 countries that are globally inclusive and regionally representative, allowing us to study the impact of various initiatives and policies on quantum readiness. As well, our research spanned 13 industries with varying levels of quantum computing activity, investments, and ecosystem partnerships.

Overall, our Quantum Readiness Index (QRI) indicates low levels of readiness across all industries and regions: 22 on a 100-point scale (see Figure 8). The QRI is based on 45 indicators across operations, technology, and strategy (see Figure 9).

FIGURE 8

Overall QRI results

Readiness across all measures is low

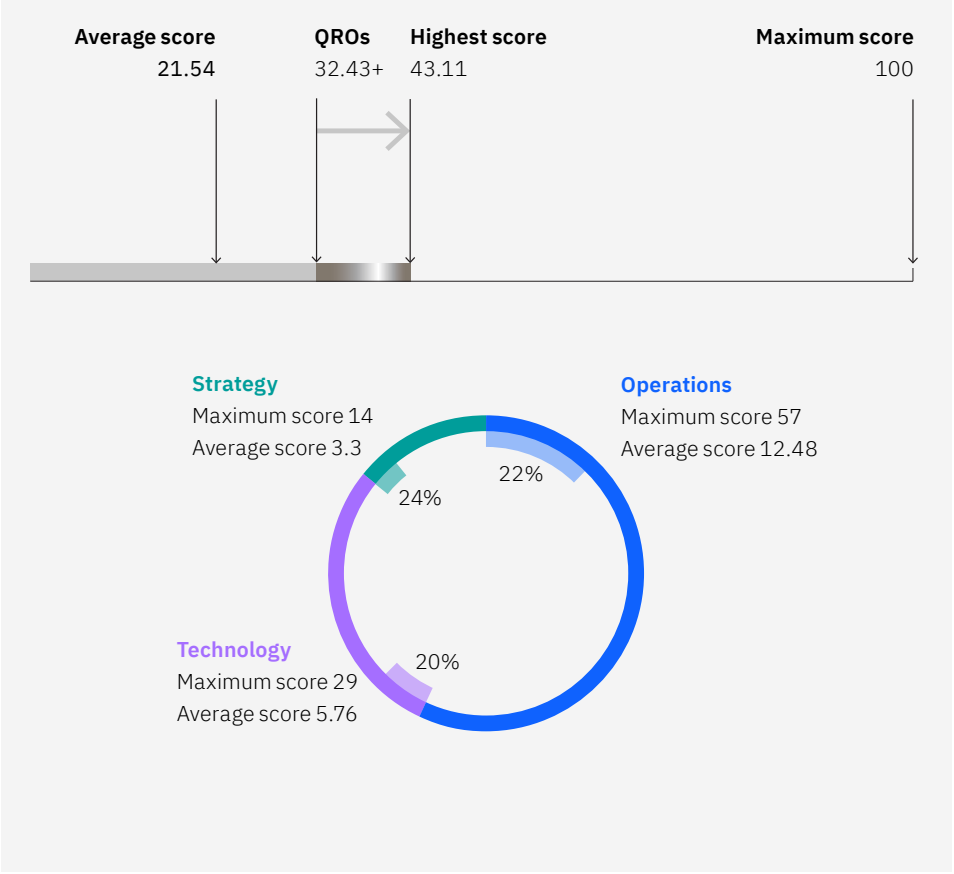
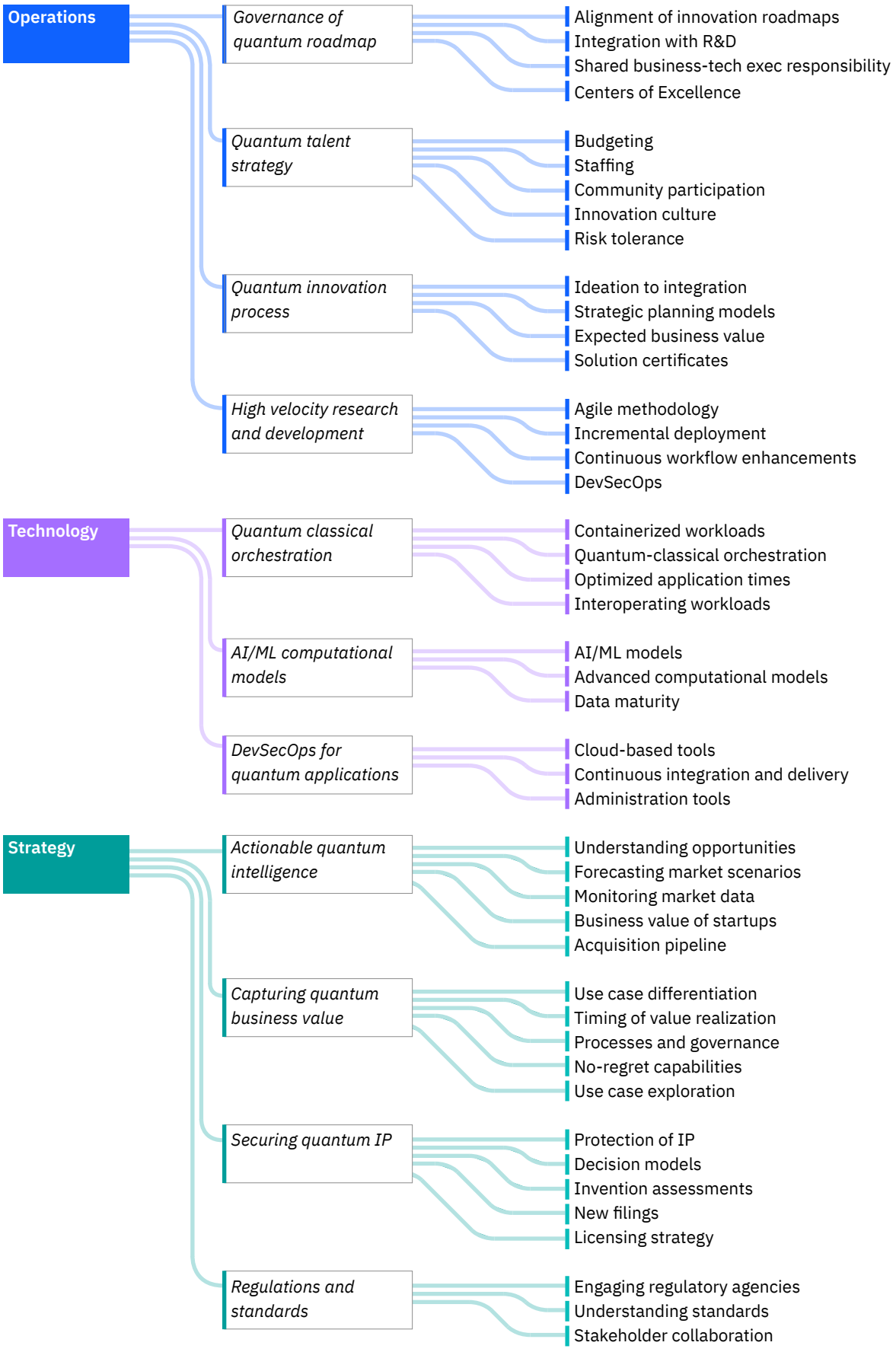


FIGURE 9

The Quantum Readiness Index



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The Quantum Decade

The Quantum Decade: A playbook for achieving awareness, readiness, and advantage. Fourth edition. IBM Institute for Business Value. December 2023. https://ibm.co/quantum-decade

Security in the quantum computing era

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