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Energy

Energy, compute and the quantum era

What quantum technologies mean for energy experts confronting the compute transition

Credits

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2026

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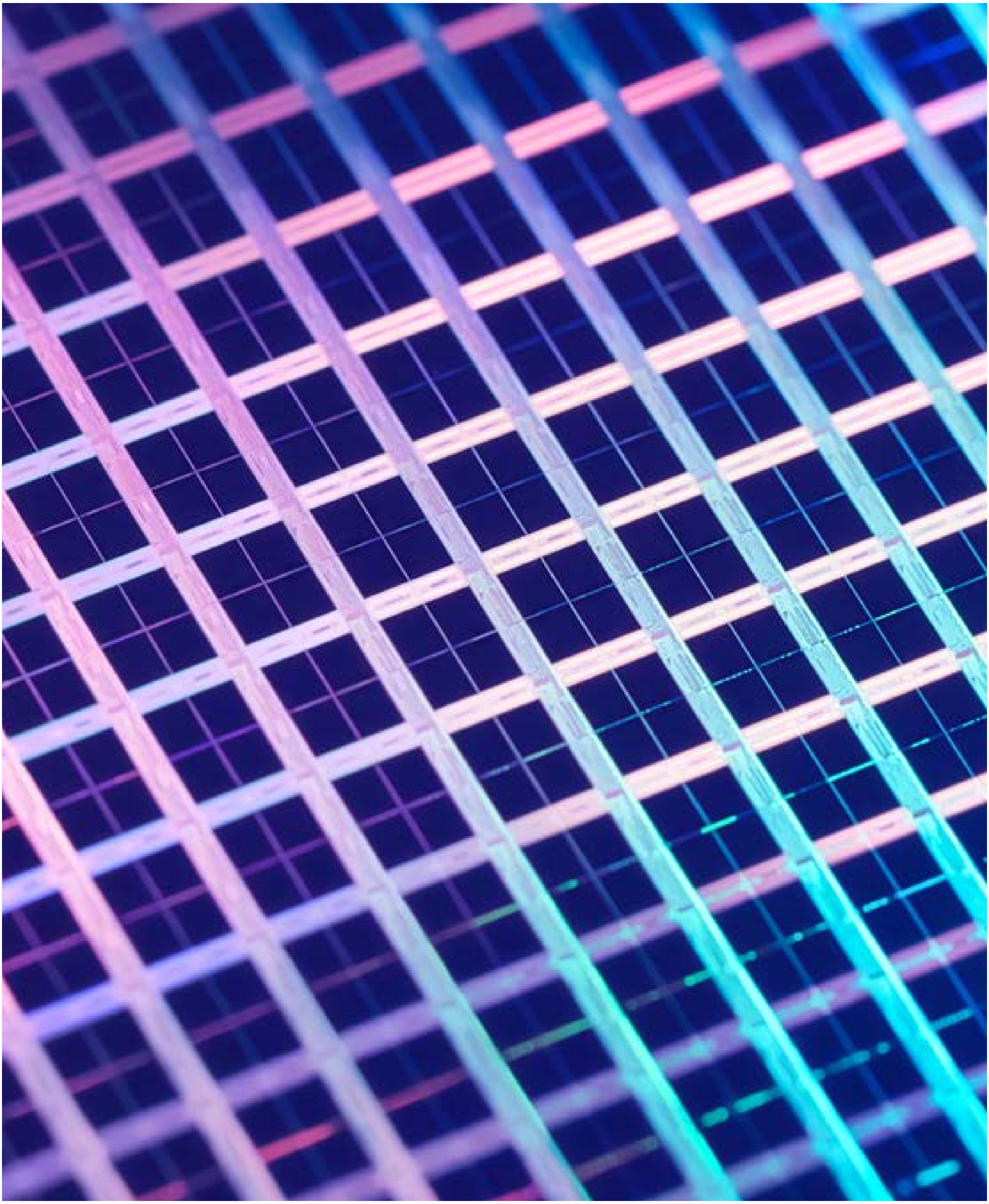

Contents

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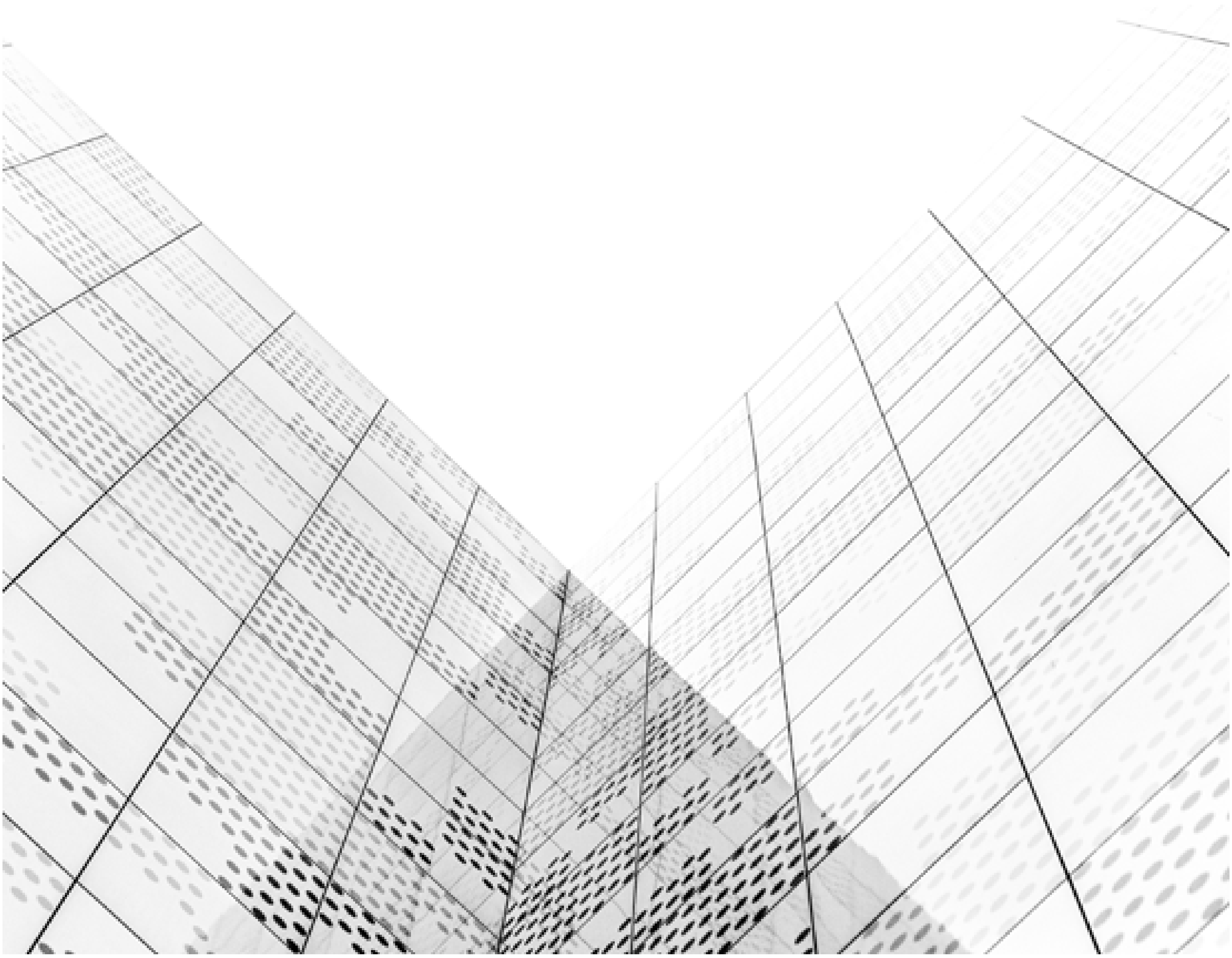
Foreword

The quantum computing conversation has shifted from potential to evaluation. Progress at the hardware and algorithm level has reached the point where grounded assessment is possible, even as large-scale deployment remains years away.

That means the question for technology leaders is no longer whether to pay attention—it is how to build the technical literacy and architectural readiness to assess quantum honestly and evaluate it responsibly alongside existing AI and high-performance computing investments.

This report helps with exactly that. It cuts through the speculation to examine where progress is tangible, where constraints are real, and which signals to look out for. Developing that understanding early creates the foundation for long-term strategy and the knowledge to act with confidence as the technology evolves.

– Jake Yang, Chief Technology Officer,
S&P Global Energy



Executive Introduction

A new wave of advanced computing is moving from research labs into strategic planning conversations: quantum technology.

Quantum computing is not yet a broad commercial platform, but it is no longer theoretical. It has emerged as a strategic imperative for the energy sector. Public and private investment are accelerating, national strategies are emerging, and enterprise awareness is expanding. In my discussions with global energy executives, and through the lens of my technology background, it is increasingly clear that quantum is seen not simply as incremental, but as a potential step change in solving the industry's hardest problems. Experts believe that in areas such as materials science and complex system optimization, quantum could prove even more transformative than AI in the long run.

Classical computing, even at hyperscale, struggles with certain molecular, materials and optimization problems critical to long-term energy sector innovation. Quantum's early impact will be targeted and complementary. It will not replace AI or high-performance computing. Instead, it may unlock capabilities in areas such as advanced materials discovery, development of more efficient catalysts for green hydrogen, high-capacity battery chemistries, grid optimization under uncertainty, carbon capture chemistry, nuclear engineering and complex reservoir modeling. At the same time, quantum infrastructure introduces new considerations for data center design, including cryogenics and power systems.

This report explores the convergence of quantum readiness, infrastructure deployment and national security. For energy leaders and policymakers, the message is clear: The transition to a sustainable world is a data-intensive journey, and quantum computing is the engine that will power it. The report highlights areas where tangible progress has been made, places where expectations still exceed capability, and pragmatic steps that energy stakeholders can take to prepare. Quantum's influence will unfold over years, not quarters. Strategic groundwork should begin now. Leaders who understand this trajectory will be better prepared to capture the opportunity and manage risk in an increasingly compute-driven energy system.

– Atul Arya, Senior Vice President and Chief Energy Strategist, S&P Global

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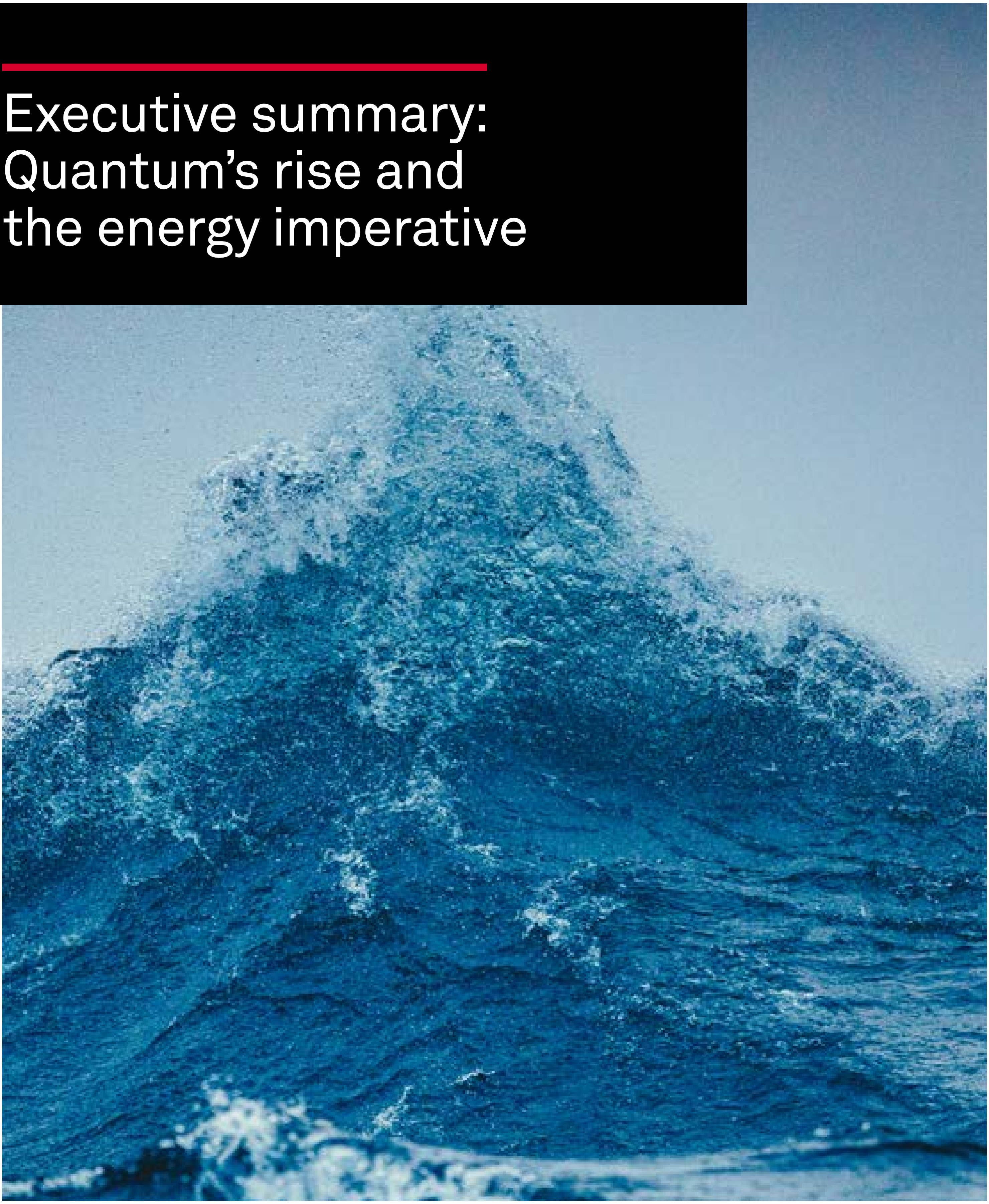
Executive summary: Quantum's rise and the energy imperative



Quantum computing and quantum technologies apply the principles of quantum mechanics to process information and measure physical systems in fundamentally new ways. By using qubits that can represent multiple states at once, quantum computers open new approaches to complex optimization, simulation, and modeling challenges across computing, security, and energy systems.

Why quantum computing matters now

Over the past decade, quantum computing and the broader quantum landscape have undergone transformative growth. No longer confined to the realm of science fiction — or even academic research — quantum computers have taken the plunge into the world of commercialization. Systems have become more powerful, use cases have proliferated, systems have been deployed to data centers and general interest has been piqued.

As quantum computers have moved out of the lab and into the market, an entire landscape has sprung up around them. From quantum networks building out an early quantum internet, to quantum-secure communication and even quantum sensors, quantum seems to be everywhere these days. We find ourselves in the earliest stages of the era of quantum utility — where foundational systems are transitioning toward practical use.

2025 ignited interest. 2026 is triggering change.

In June 2024, the United Nations proclaimed 2025 as the International Year of Quantum Science and Technology (IYQ). The motion was made in response to a global push from national scientific societies to commemorate 100 years of progress in quantum mechanics, a field whose birth is often set in June 1925 with Werner Heisenberg's first formulation of quantum theory. The early work of notable physicists set the stage for the quantum technology we see today, and while a hundred-year anniversary is worth celebrating, the UN's timing served an added purpose: Quantum technologies had been teetering on the edge of global prominence, and dedicating a year to the celebration of quantum tech served as a strategic visibility effort to spur widespread awareness, interest and funding for the nascent industry.

It worked.

Only a few months into 2026, the quantum computing industry has been catalyzed: M&A activity is surging, investment continues to grow, governments around the world are accelerating their commitment to quantum technology, and deployment and commercial conversations are increasingly supplanting hypotheticals.

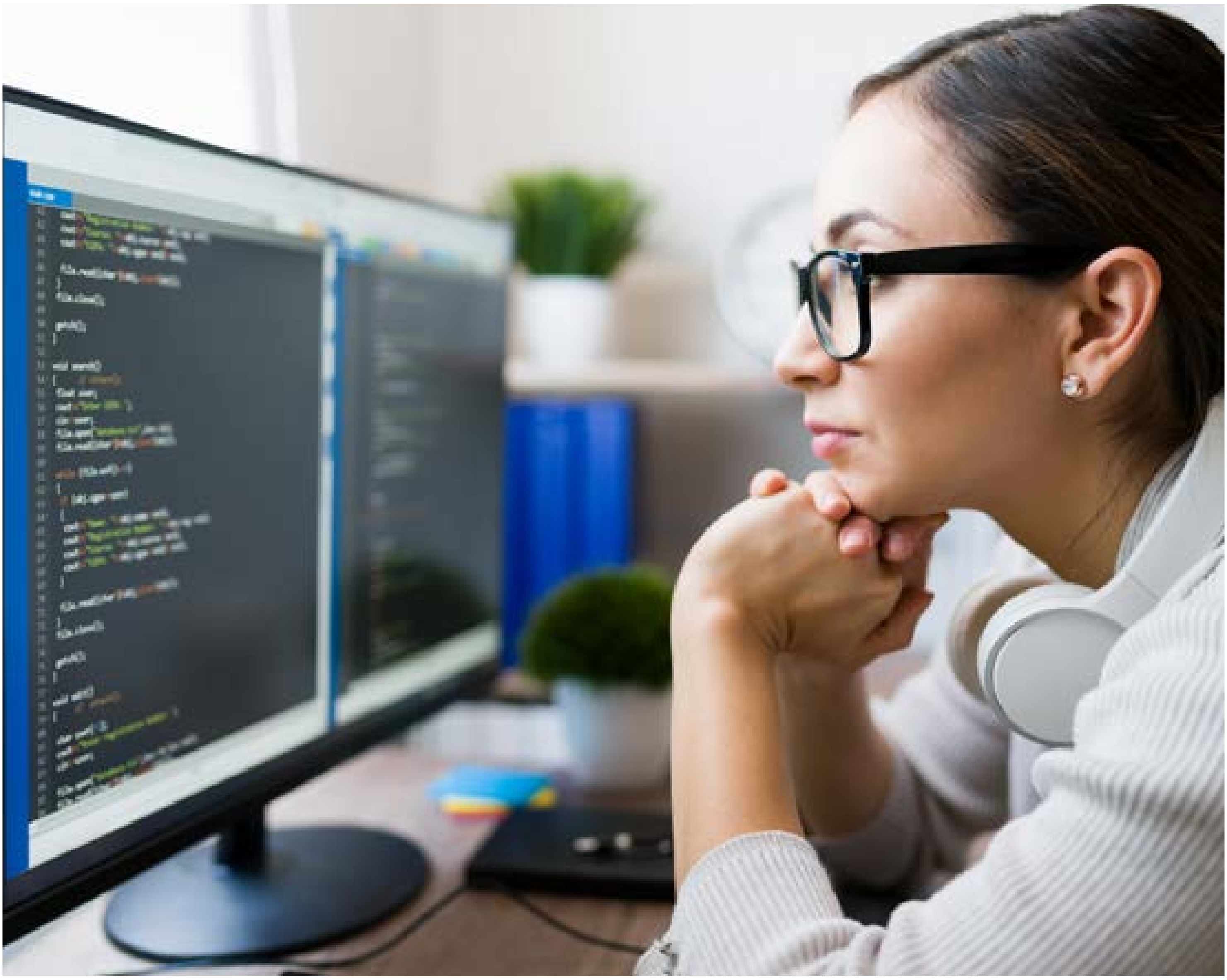
> **"Quantum computing is starting to be used for real-world problem solving. Partnerships between national laboratories and quantum vendors—including work by Oak Ridge National Laboratory and IonQ on power grid optimization—highlight how early quantum systems are already being tested on complex energy challenges."**
>
> — 451 Research analysts

Quantum computing as a strategic technology for future energy systems

The realms of computing and energy have become increasingly intertwined. While much of today's discussion centers on AI, quantum computing sits on the same compute continuum, introducing new computational approaches designed to tackle harder, more complex problems. Quantum offers new tools and schemas to solve existing challenges more efficiently or answer net-new questions in the energy space. These include:

- System optimization at scale: Quantum computing could enable more advanced optimization of power grids, supply chains and energy markets as system complexity and compute intensity increase.
- Accelerated modeling and materials discovery: Emerging quantum capabilities may improve simulation of complex physical systems, supporting advances in batteries, catalysts and low-carbon energy technologies.
- Infrastructure, security and readiness implications: As quantum systems progress toward deployment, energy operators will need to account for new infrastructure requirements, cybersecurity risks and workforce needs.

Quantum computing has substantial implications for the energy systems of the future — implications that can guide organizational strategies when explored and discussed today.



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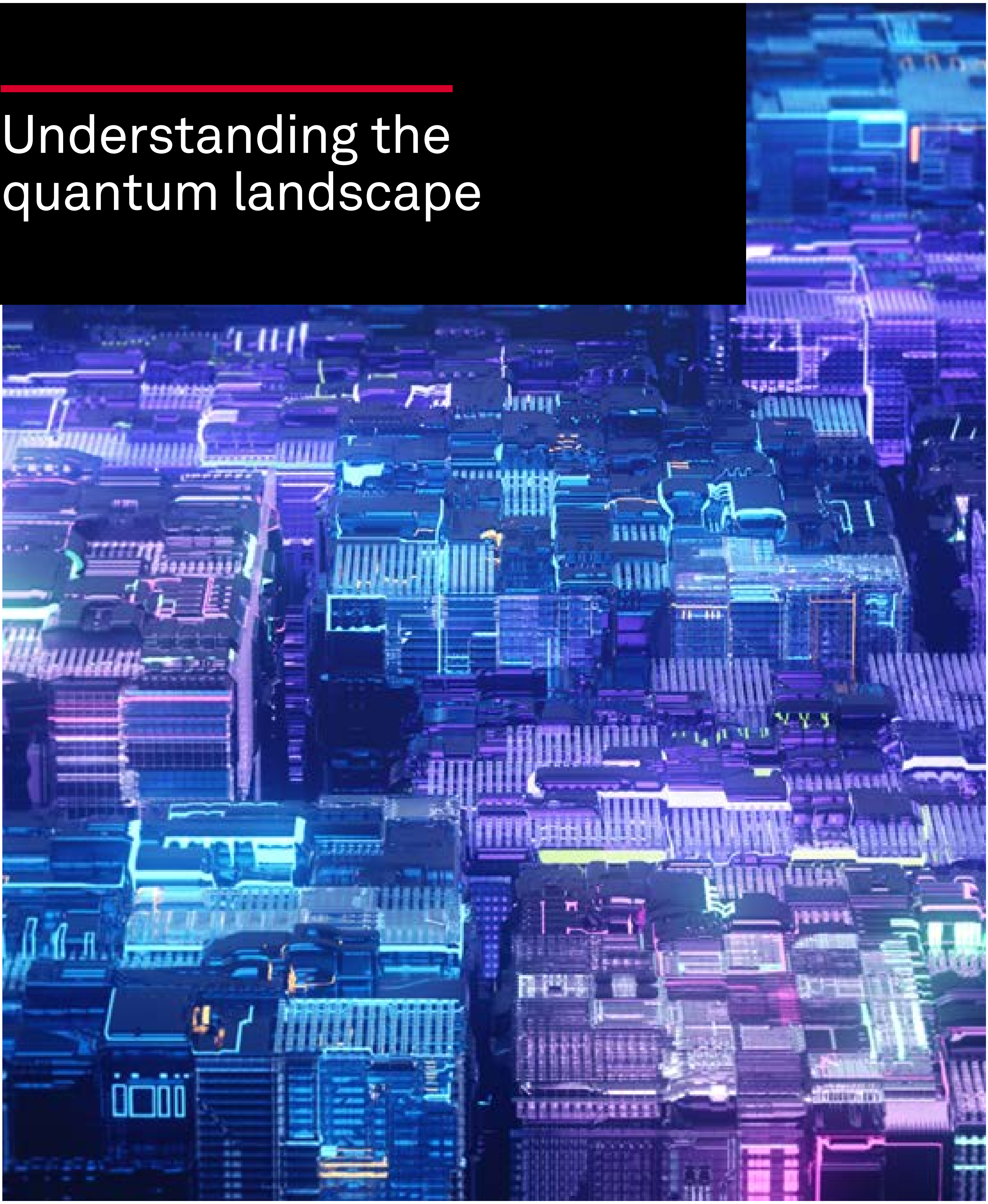
Understanding the quantum landscape



Quantum is more than just compute

When the word "quantum" enters a conversation, it can refer to many things. Broadly, however, quantum technologies apply principles of quantum mechanics (the physics of subatomic particles) to harness the unique properties of these particles for novel applications. While quantum computers are one of the most well-known technological applications of quantum mechanics, the quantum landscape also includes networks and communication, security applications and environmental sensors.

Quantum computing

This subset of computer science uses quantum mechanics to build powerful computers to solve problems that are difficult or impossible to solve using classical computation techniques. Quantum computers harness a unique property of subatomic particles known as superposition: the ability to exist not just in a single state, but in multiple states at once. In computing, that correlates to a computer that, rather than using a bit (0 or 1) to represent data, uses a qubit, which can be both 0 and 1 at the same time. The field of quantum computing encompasses hardware vendors building quantum computers, software vendors specializing in quantum-specific developer tools, and quantum computing-as-a-service (QCaaS) providers leasing access to quantum computers, usually via the cloud.

Quantum vendor types

Quantum computing is being pursued by more than just lab-grown startups. Vendors in the quantum computing ecosystem include:

- Private, quantum-first hardware companies: venture-backed firms focused primarily on building quantum computing hardware, often centered on a specific qubit modality
- Public, quantum-first companies: publicly traded firms whose core business is quantum computing, typically spanning hardware, systems integration and early commercial services
- Diversified technology companies (Big Tech): large, established technology firms investing in quantum computing as part of a broader portfolio that includes cloud, AI, semiconductors and high-performance computing (HPC)
- Cloud service providers: vendors offering access to quantum hardware and simulators via cloud platforms, often positioning quantum as part of a hybrid compute stack
- Quantum software and algorithm developers: companies focused on quantum programming tools, compilers, algorithms and application-layer software, often hardware-agnostic
- Quantum networking and communications vendors: firms developing quantum key distribution (QKD), quantum repeaters and early quantum internet infrastructure
- Quantum sensing and metrology companies: vendors applying quantum effects to sensing, timing, navigation and measurement, with nearer-term commercial applications than computing
- Systems integrators and professional services providers: organizations supporting quantum adoption through consulting, system design, integration with classical infrastructure and pilot deployments
- Government-backed or national lab-adjacent entities: research-driven organizations operating at the intersection of public funding, defense and early-stage commercialization
- Hybrid computing and enabling technology vendors: companies supplying cryogenics, control electronics, photonics, materials or other critical components required to operate quantum systems

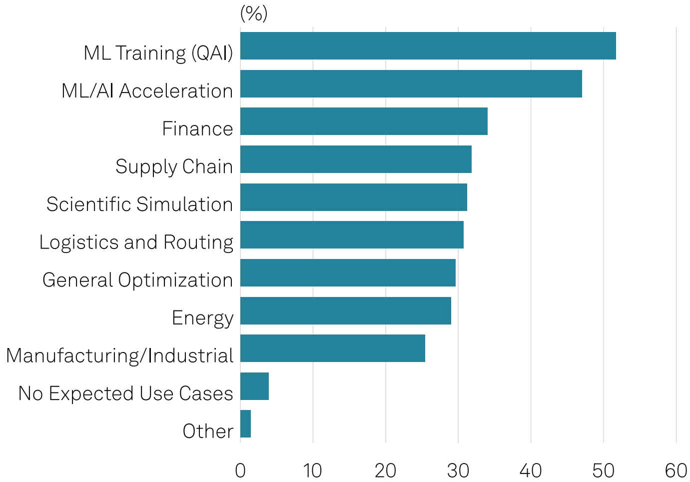
Key use cases and early adopting industries

One of the biggest shifts over the past decade in the realm of quantum computing has been the emergence of early use cases for the technology. While quantum computers have plenty of runway for further development, current systems are already being used in what has been termed the "era of quantum utility." Today's early quantum computers are functional rather than simply theoretical and are well-suited to solve problems requiring ultra-high-powered computing resources in various industries, including:

- Finance
- Chemistry and Pharmaceuticals
- Communication and Security
- Sustainability
- Energy
- AI and ML

Quantum computers are particularly good at solving problems in optimization, modeling and simulating nature. In general, the more complex a problem, the better a quantum system performs compared to classical methods.

AI and ML use cases top organizational anticipation for quantum computing workloads



Q. For which of the following use cases does your organization expect to run workloads on quantum computing hardware in the future?
Please select all that apply.
Base: All respondents (n=362).
Voice of the Enterprise: Digital Pulse, Emerging Technology - Quantum Computing 2026.
Source: 451 Research from S&P Global Energy Horizons.
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Quantum + AI

Given the intense recent focus on artificial intelligence, it is no surprise that opportunities have begun to proliferate for collaboration between quantum computing and AI tools. Organizations merging quantum with AI include tech giants such as Google, IBM, Microsoft and Amazon (AWS), as well as quantum-native companies including Quantinuum, IonQ, Rigetti and Xanadu.

For potential quantum users, AI and ML remain top-of-mind in their quantum planning: In a Voice of the Enterprise survey on quantum computing conducted by 451 Research from S&P Global Energy Horizons, respondents placed quantum-enhanced machine learning model training (also known as quantum artificial intelligence, or QAI) and quantum-powered acceleration of AI/ML inferencing as the top two quantum use cases for their organizations.

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Industry momentum

Key themes and sector challenges

The past year has marked a watershed moment in the field of quantum technology, with recent advances and global initiatives piquing public interest and injecting both optimism and urgency into the sector. Public perception about the potential of quantum computing specifically is very high: Respondents to 451 Research's Voice of the Enterprise: Digital Pulse, Quantum Computing 2026 survey overwhelmingly anticipate quantum computing will begin producing material value for their business imminently.

Within the broader momentum of the quantum computing space, a few key themes are driving industry discussions and shaping the market trajectory.

> **"76% of enterprise respondents believe quantum computing will begin producing material value for their business within the next 5 years."**
>
> — 451 Research's Voice of the Enterprise: Digital Pulse, Emerging Technology - Quantum Computing 2026

Fostering quantum talent

Quantum computing in its current iteration requires a unique, highly technical skill set. Current employees at quantum vendors are often equipped with a Ph.D. in physics, quantum mechanics or photonics, or other advanced scientific degrees. As quantum begins to scale, there is concern that the lack of a quantum-skilled workforce could limit industry progress. To address this issue, many quantum vendors have collaborated with educational institutions to help develop curriculum, host hackathons and fund educational outreach. There has also been a push throughout the industry to develop bridge technologies to help make quantum computers more accessible to today's classically trained computer scientists and engineers, minimizing the need to retrain those workers in deep science.

Government investment

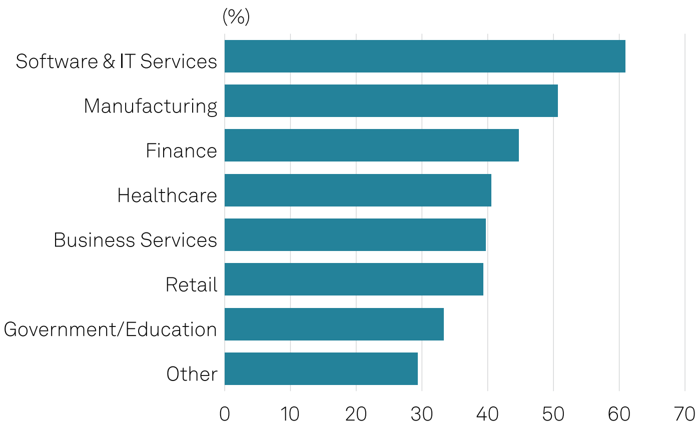
Government funding and support for the nascent quantum computing industry remain critical. While much of the conversation around national quantum initiatives has focused on North America, Europe and Asia, additional geographies are also engaging with the quantum computing space, with support initiatives announced from Brazil to South Africa. Much of the motivation behind government investment in quantum technologies appears tied to the twin issues of national security and technological supremacy.

Quantum tech in the boardroom

Industry discussion and conferences in the quantum sphere have shifted to focus on the end-user side of quantum. Executives and engineers from various industries are already showcasing proof-of-concept projects in quantum, with some integrating early quantum systems into their workflows to solve real-world business problems.

Some industries have been more eager to test out early quantum systems than others, with finance, manufacturing and healthcare often touted as particularly good fits for quantum use cases. This aligns with our Voice of the Enterprise: Digital Pulse, Emerging Technologies 2025 survey, in which software and IT services, manufacturing and finance organizations indicated the strongest intent to invest in quantum computing, with healthcare a close fourth.

Software & IT services, manufacturing and finance show the strongest intent to invest in quantum computing



Q. For each of the following technology areas, please indicate your organization's current level of intention to invest in or assign budget to engaging with technology that is currently in the experimental or developmental stages (including R&D, consulting, and buying technology). Please use a scale from 0 to 10, where 0 is not intending to invest and 10 is strong intent to invest: Quantum computing.
Base: All respondents (n=604).
Voice of the Enterprise: Digital Pulse, Emerging Technologies 2025.
Source: 451 Research from S&P Global Energy Horizons.
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Scaling

While the past year brought a rapid increase in the size and power of quantum systems, the race is far from over. More powerful systems remain the order of the day, and they will come only through a combination of larger qubit configurations and more performant qubits. Industry voices generally estimate that commercially useful quantum systems will begin to proliferate before the turn of the decade. However, many nuanced caveats complicate such projections. For example, quantum annealers — a type of narrowly useful quantum computer — are already being used commercially, and progress in quantum computing has grown more rapidly over the past year than expected. Moreover, quantum's "ChatGPT moment" may not arrive with one big bang of adoption; implementation might instead grow over a sustained period of several years. In any case, the near future holds the promise of larger, more powerful and more broadly useful quantum computers.

Cryptography and cybersecurity

While quantum computing shows great potential to tackle big problems, the technology's development also has a dark side: Projections indicate that sufficiently powerful quantum computers could break current encryption methods, making leadership in quantum computing not just a technical "nice to have," but a national security issue. Given the rapid progress of quantum computing power over the past few months alone, there is a heightened sense of urgency behind efforts to develop and implement quantum-proof encryption methods and shore up national quantum capabilities. There has also been more discussion around areas that might be particularly vulnerable to quantum-enabled attacks, including the Bitcoin blockchain.

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Insider insights

The following perspective was provided by IBM.

IBM’s take on the evolving quantum landscape

“IBM is building the future of computing by bringing useful quantum computing to the world.

Quantum computing is a new compute architecture that encodes and manipulates information using the same mathematics that govern the behavior of interacting atoms and molecules. IBM is a leader in quantum, bringing this new hardware to life as part of a quantum-centric supercomputing workflow—one where quantum acts as an accelerator to existing CPU and GPU-based systems.

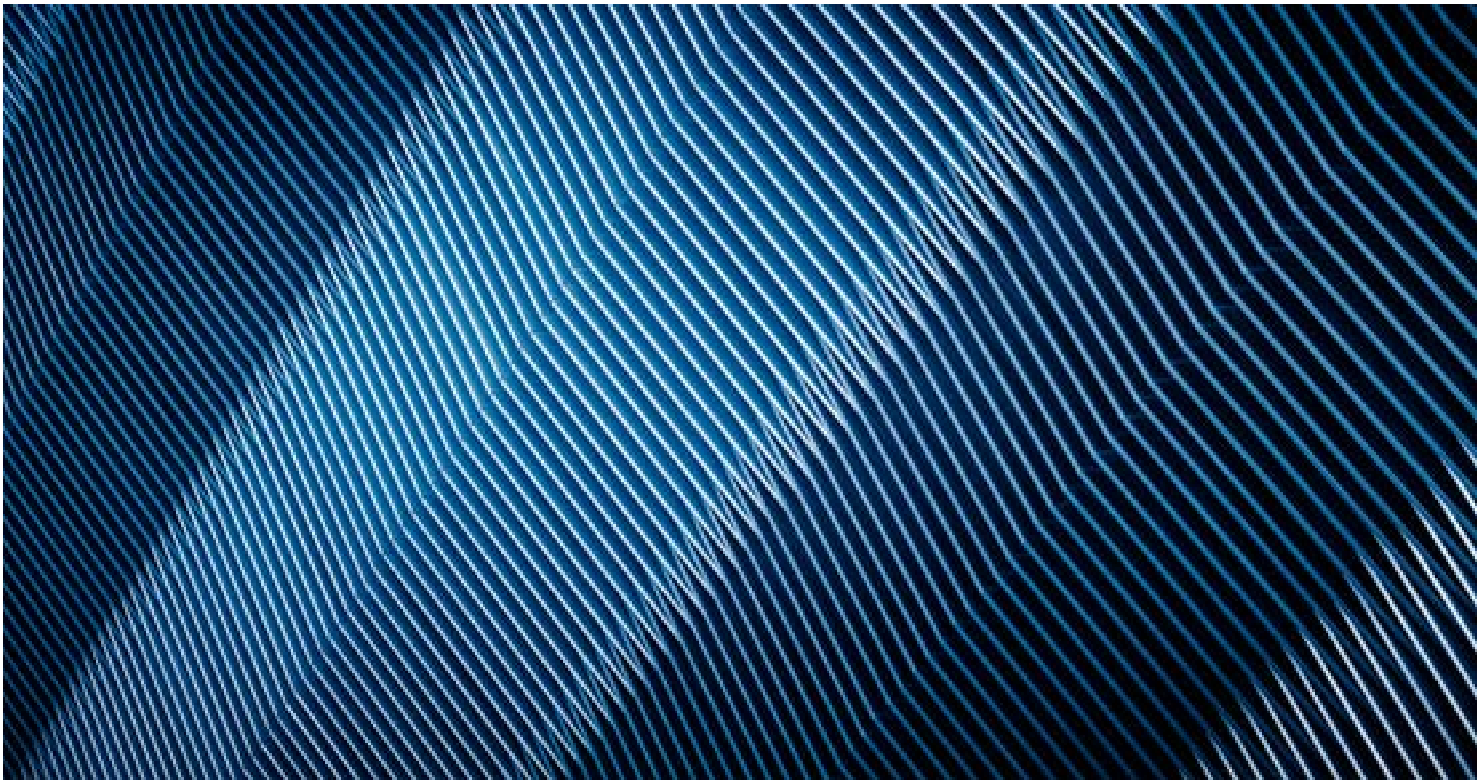
Today, IBM is fostering a global network of clients and partners already researching potentially revolutionary use cases. Based on their research, quantum is poised to directly address bottlenecks that energy companies face when developing new materials or optimizing complex processes.

For example, researchers at IBM and Oxford, the University of Manchester, ETH Zurich, École Polytechnique Fédérale de Lausanne, and the University of Regensburg recently built a molecule from scratch and then studied its properties using a quantum-centric supercomputing algorithm. RIKEN scientists are modeling electronic structure, reaction pathways, excited states, and catalytic behavior as part of a new quantum + HPC workflow. Researchers from Zuse Institute Berlin and Los Alamos National Laboratory recently joined IBM to study a quantum multi-objective optimization algorithm for processes, supply chains and commodity pricing that offers the potential for speedups over today’s best methods. And a team from The Hartree Center, E.ON, and IBM are exploring quantum algorithms to decompose weighted graphs for optimization.

We see logical pathways to extend this research to energy-relevant applications including new battery materials for extended storage capability, new catalysts to reduce emissions, grid optimization for energy contracts between producers, prosumers, and consumers, and more.

The field is accelerating fast, and we expect the first quantum advantages to emerge in the near term. IBM offers a suite of access plans to the world’s highest-performing quantum computers and engagements to guide companies kicking off their quantum explorations. For the energy industry, there’s never been a better time to get started.”

– Scott Crowder, Vice President: Quantum Adoption and Business Development, IBM



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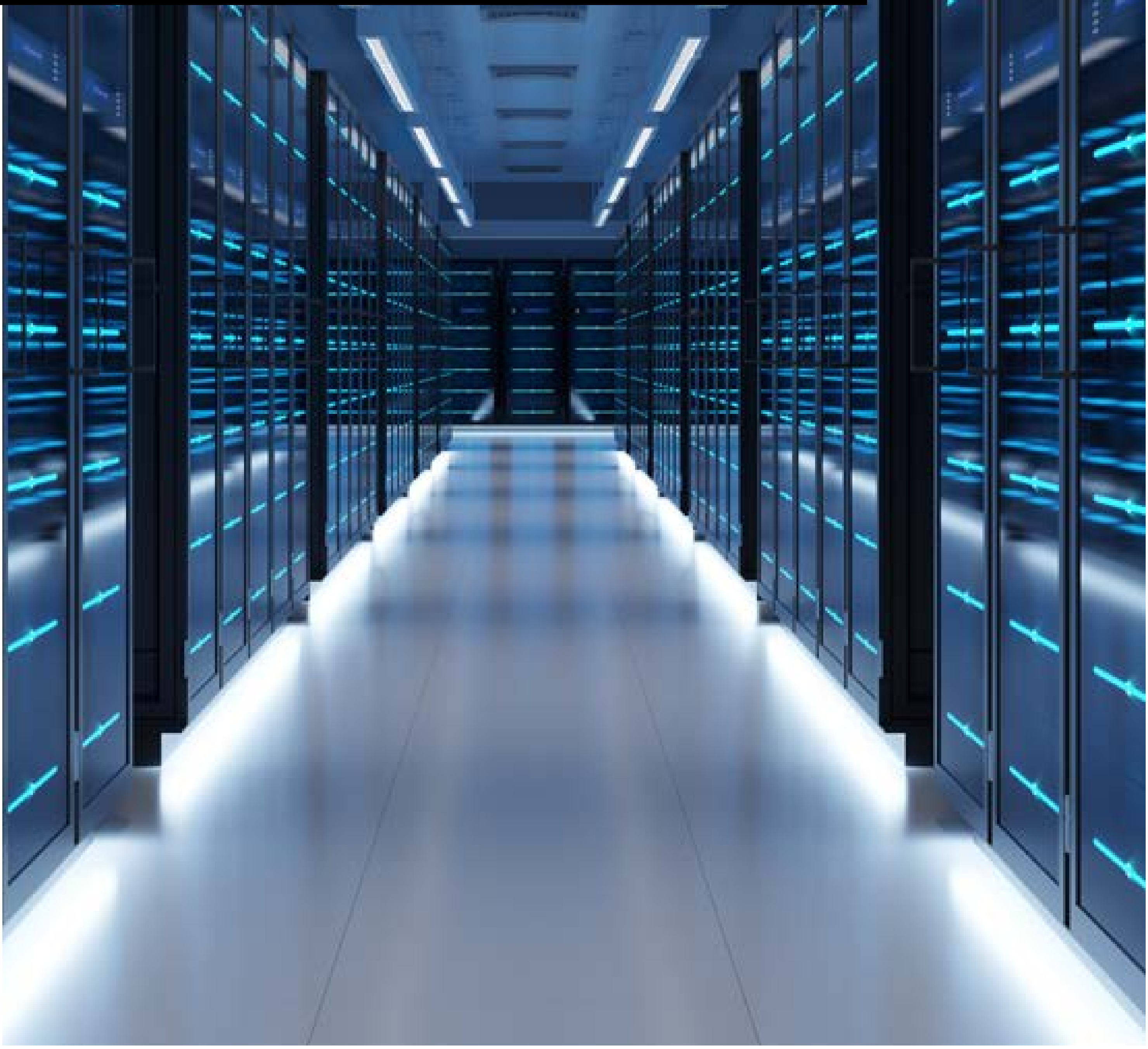
Quantum computing & data centers



A new generation of compute infrastructure

After several stages of development, intermediate-scale quantum systems are now available for purchase and are in use globally, with an estimated 2025 market revenue of $2.5 billion and a projected 2026 market revenue of nearly $9 billion. In 2025, global investment in quantum technology surpassed $55 billion, and many quantum vendors plan to release fault-tolerant quantum systems (high-powered, commercially targeted computers designed to run at scale) between 2028 and 2030.

While quantum computing capability is accelerating rapidly and influencing business decisions today, the next few years will present a new set of challenges for the burgeoning industry. Even the best technology will falter if access is constrained, and careful system packaging and deployment will be critical to the widespread adoption of quantum computers for commercial applications. Realizing the technology's potential will require deployment at scale in quantum data centers around the world.

- The emergence of fault-tolerant quantum computing, able to detect and correct quantum errors in real time, is only a few years away. Yet significant gaps in industry knowledge and system design stand between today's data center blueprints and quantum computing integration.
- For the foreseeable future, key differences between conventional computing and quantum modalities will necessitate uniquely customized quantum data center environments.
- Quantum system deployments remain primarily centered in research-oriented environments, although a shift is taking place as hyperscalers, telcos and governments begin to acquire and prioritize quantum computing infrastructure, with quantum hubs emerging in high-value, high-expertise locales.

> **"In 2025, global investment in quantum technology surpassed $55 billion."**
>
> — 451 Research analysts

Quantum deployment environments

A common misconception among those new to the quantum computing space is that there are no commercially deployed quantum systems. In fact, various types of quantum computers have been installed and are in use around the world, although deployment details vary.

The academic roots of quantum computing remain evident in the deployment patterns of today's systems, which often originate in universities, HPC centers or national labs. More mature quantum computing modalities have migrated to the cloud, with remote access to quantum systems available via hyperscale cloud providers and quantum vendors themselves. Many of today's intermediate-scale systems are also deployed in on-premises settings, with quantum simulators, annealers (built for specific types of optimization-related calculations rather than general-purpose computing) and superconducting quantum systems commonly deployed. Trapped-ion, photonic and neutral atom systems are also nudging into the space.

Quantum deployments vary based on hardware modality type and maturity

Labs and HPC centers have the most available system options, but cloud access to quantum compute is also readily available

Modality	University Labs	HPC / National Lab Centers	Quantum Vendor Cloud	Hyperscaler Cloud	On-Premise / Dedicated Installations	Colocation Data Centers	Telco Providers
Hybrid / Simulators	Available	Available	Available	Available	Available	Available	Available
Quantum annealing	Available	Available	Available	Available	Available	Emerging	Emerging
Superconducting	Available	Available	Available	Available	Available	Emerging	Rare
Trapped-ion	Available	Available	Available	Available	Emerging	Emerging	Rare
Photonic	Available	Emerging	Available	Available	Emerging	Emerging	Emerging
Neutral atom	Available	Available	Available	Emerging	Emerging	Emerging	Rare
Other / Emerging (spin, topological, cat, diamond)	Available	Available	Rare	Emerging	Rare	Rare	Rare

Data compiled: September 22, 2025.

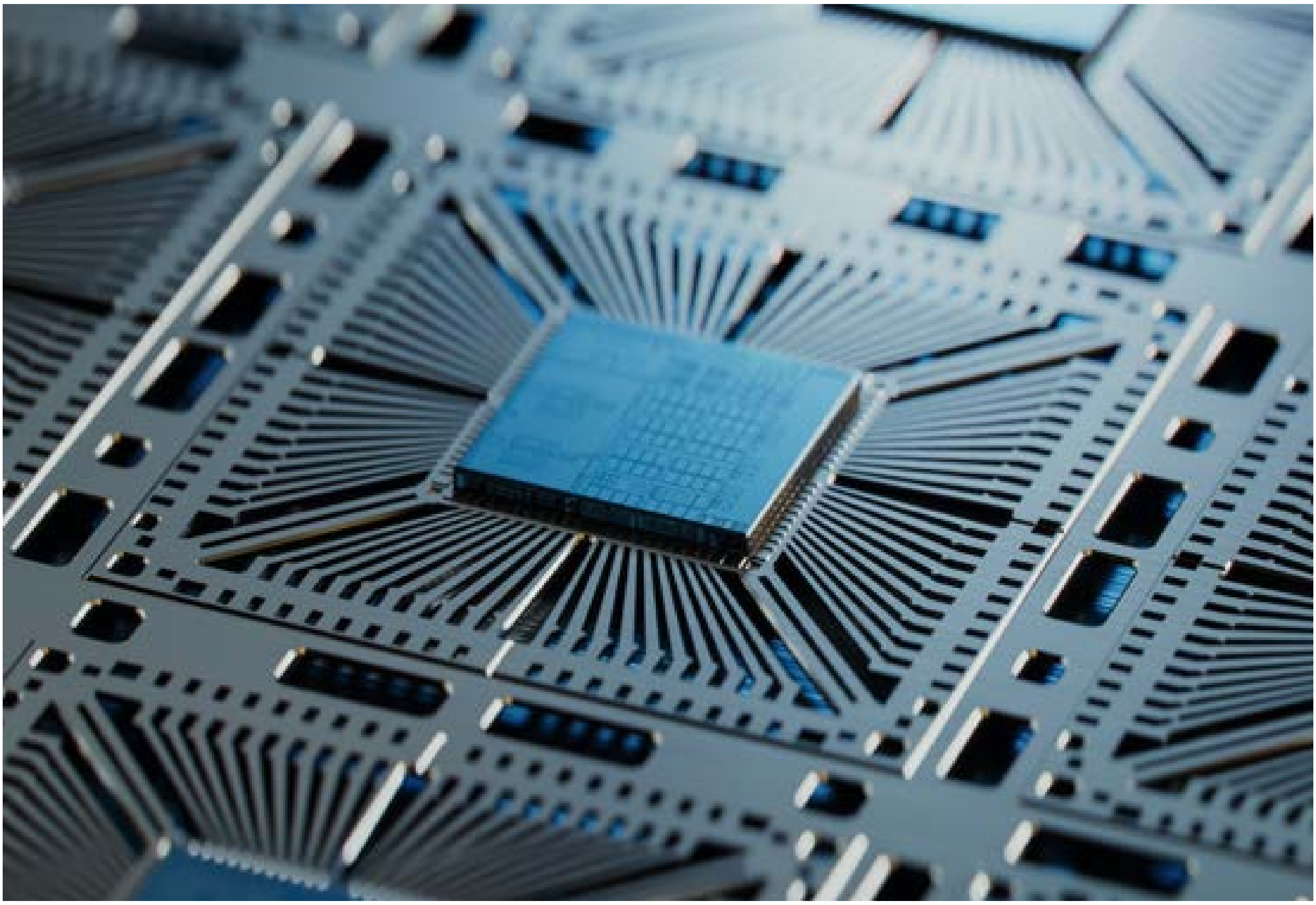
Source: S&P Global Energy Horizons 451 Research Quantum Market Research

Quantum deployment considerations

Depending on the modality, the unique technical requirements of quantum systems may hamper the transition of quantum computing into data centers. Quantum systems can vary substantially in size, weight, form factor, energy use, cooling requirements, environmental conditions, connection and port locations, and network connectivity requirements. There is no set standard for quantum system construction, making every quantum computing deployment an exercise in custom construction.

Some of the more mature quantum system architectures include superconducting qubits, built using cryogenically cooled superconducting circuits; photonic systems, which use photons manipulated via optical components; neutral atom qubits, built with neutral atoms held in place with optical tweezers and manipulated using lasers; and trapped ion qubits, which use ions held in place by electromagnetic fields and manipulated by lasers. Across these four leading modalities, installation considerations vary greatly, even across different providers' systems built in the same modality. While all systems must address scalability, control electronics, interconnections, power demand and more, additional deployment considerations are unique to systems of different classes.

> **"With no set standard for quantum system construction, every deployment involves bespoke, customized construction."**
>
> — 451 Research analysts



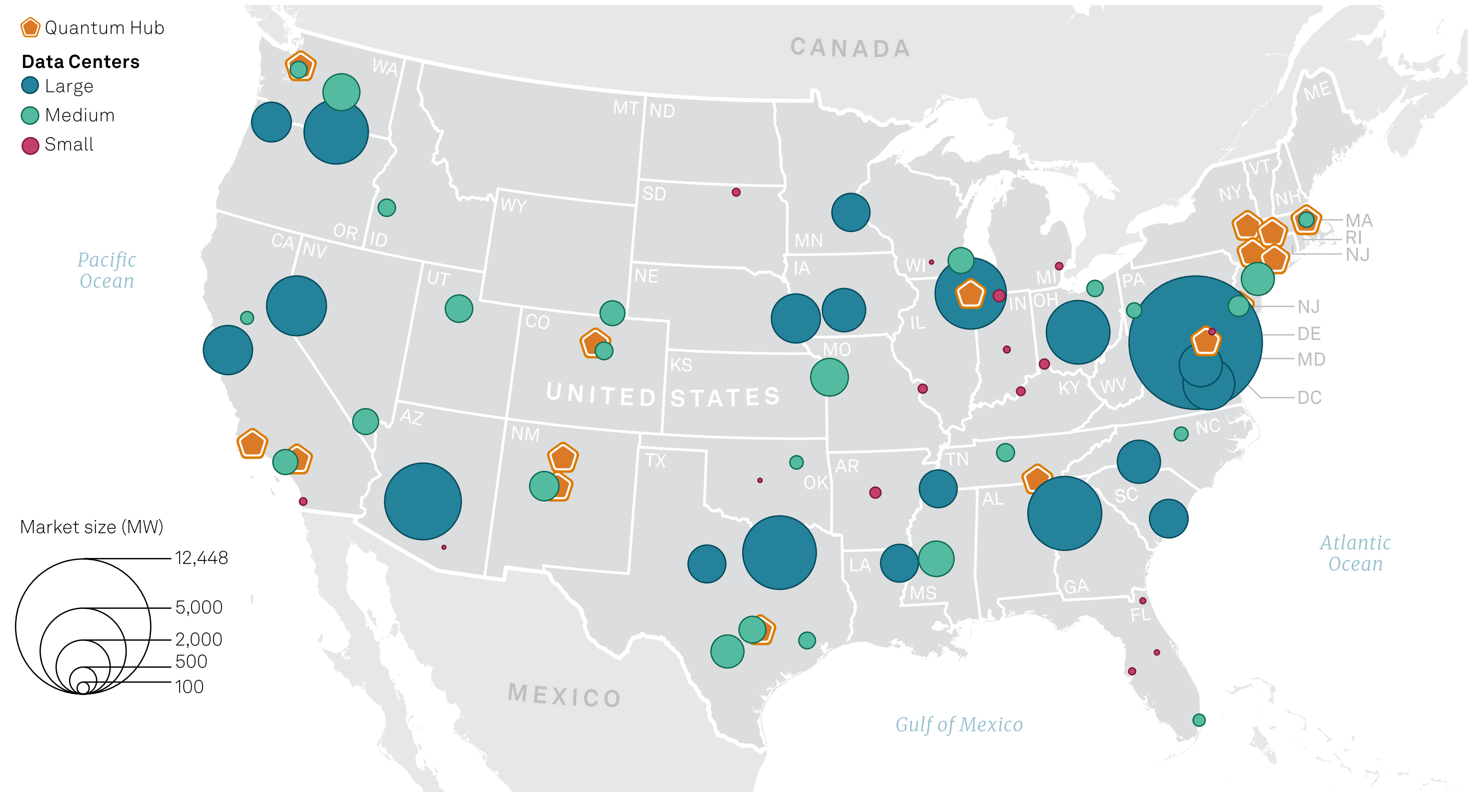
The emergence of quantum hubs

While quantum computers are available around the world through various deployment methodologies, there has already been a consolidation of talent and accessibility into quantum hubs at strategic locations.

The United States offers a unique view into some of the forces driving geographic capability in quantum computing, with hubs forming in locations with deep quantum expertise, a strong talent pipeline, local support and investment, and an existing supply chain. Cities such as Chicago, Illinois; Boulder, Colorado; Boston, Massachusetts; Santa Barbara, California; Chattanooga, Tennessee; and Poughkeepsie, New York are emerging as leaders in quantum availability and development.

While there is some overlap with traditional data center hubs, in many cases quantum computing is gaining traction in new and distinct areas. We expect quantum computing data centers to remain near research hubs in the short term, while in the longer term, quantum computing infrastructure may need to deploy closer to data generation sites to facilitate a wider range of use cases and hybrid quantum/classical computation. As quantum data centers scale, their power, cooling and siting requirements will increasingly intersect with broader energy infrastructure planning.

Quantum hubs are forming



Source: S&P Global Energy

For more details on the intersection between quantum computing and traditional data center environments, please visit our Look Forward Journal article on the topic.

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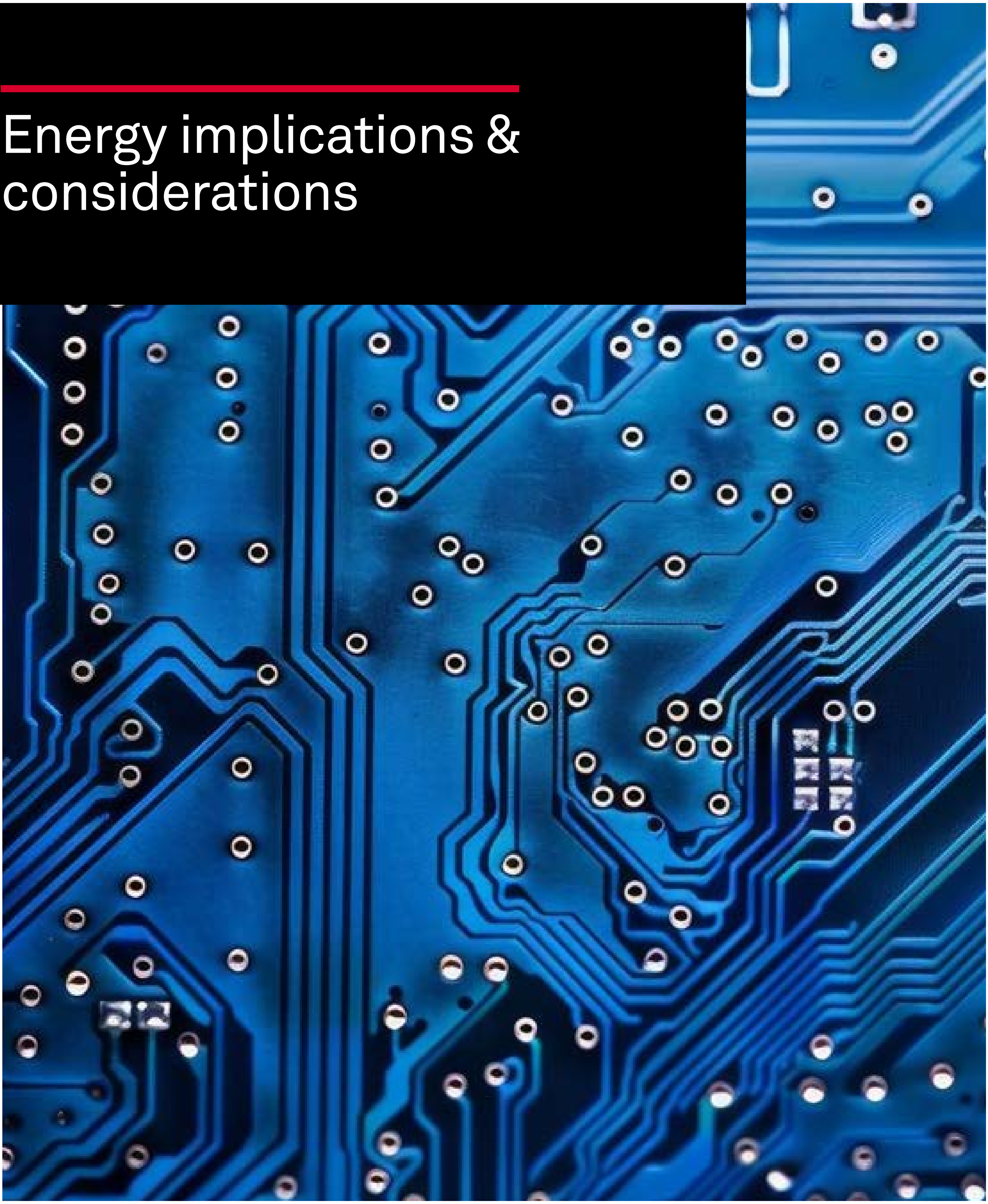
Energy implications & considerations



Connecting quantum progress to energy challenges and opportunities

The proliferation of AI has brought the tech world roaring into the energy sphere. AI is driving intense demand for computing capacity, which in turn is leading to conversations about energy load and associated greenhouse gas emissions.

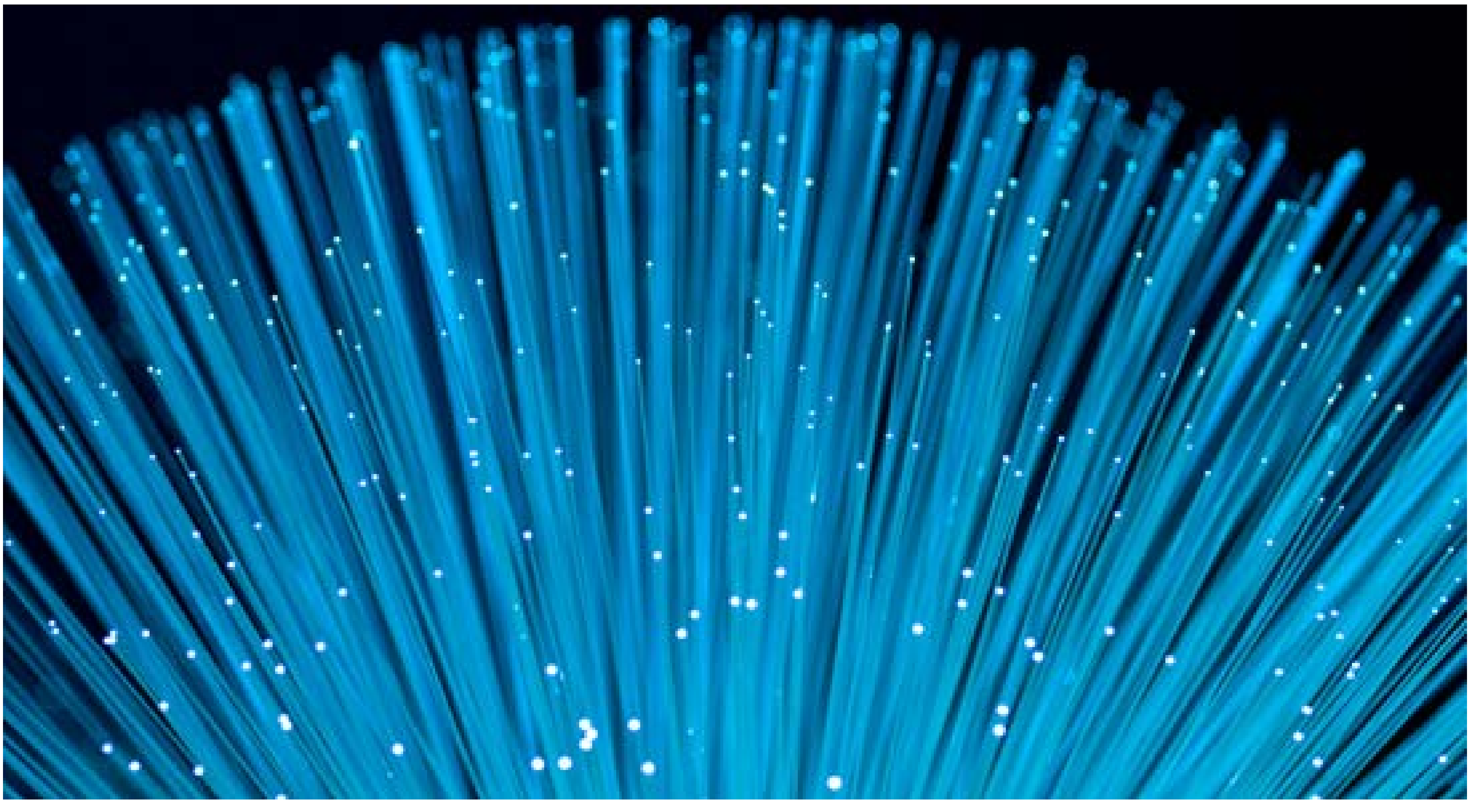
While AI might be the initial driver of discussions about the impact of computing on energy demand, quantum computing is increasingly entering the conversation — both for its potential to help address AI's energy demands in the long-term, and for its suitability in solving other energy system challenges.

Today's quantum systems, while still early in deployment, are designed to address the classes of problems associated with complex global energy system challenges. Rather than a stand-alone breakthrough, quantum computing could prove a complementary tool to augment existing digital, physical and policy frameworks.

> **"The explosive growth of AI has led to projections that global data center power demand will nearly double between 2024 and 2030."**
>
> –451 Research analysts

Policy and infrastructure alignment

National quantum strategies are increasingly intersecting with energy policy, reflecting shared concerns about security, competitiveness and infrastructure resilience. Governments view quantum capabilities as both a scientific asset and a strategic technology for economic leadership and infrastructure protection. Investment in quantum computing naturally sits alongside investment not only in advanced technologies, but also in energy-related areas such as power generation, grids, data centers and digital infrastructure. While quantum strategy and energy policy could go hand in hand, there remains the risk of misalignment should quantum technology and policy advance faster than grid, data center or skills infrastructure.



Optimization and simulation

Energy systems — whether power grids, supply chains or generation portfolios — are defined by enormous complexity, tight constraints and competing objectives. Quantum approaches could eventually improve grid operations by tackling optimization: improving dispatch, balancing variable renewable resources in real time, and reducing losses across increasingly decentralized systems. In the arena of materials discovery, quantum-powered simulation may accelerate the development of advanced batteries, catalysts and low-carbon materials. Quantum companies are already working in this space: quantum vendor IQM partnered with Volkswagen to investigate battery simulation in electric vehicles, while IonQ has partnered with Hyundai to develop new variational quantum eigensolver (VQE) algorithms to study lithium compounds and battery chemistry.

Climate modeling

Climate systems are governed by highly complex, nonlinear interactions across Earth's atmosphere, oceans and terrestrial environments, requiring enormous computational resources to model accurately over long time horizons or in deep detail. Quantum approaches could accelerate simulations involving everything from fluid dynamics to full Earth-system models, improving resolution and insight without proportionally increasing computing costs. While large-scale quantum advantage in climate modeling remains a long-term prospect, research in the area is growing, with quantum algorithm company Quanscient actively investigating both the potential of quantum computing for climate modeling, and the roadblocks still to be overcome in its implementation.

Strategic recommendations for energy leaders

- Begin preparing now for hybrid computing environments, where quantum systems complement classical and AI-driven workflows rather than replace them.
- Engage early with vendors, cloud providers, research institutions and governments to help shape standards, influence policy alignment and reduce integration risk.
- Align quantum exploration with priority energy use cases, focusing on optimization, modeling and materials challenges that map directly to your sector.
- Invest in talent development across quantum specialists and quantum-literate engineering roles to avoid workforce bottlenecks as the technology scales.
- Proactively integrate post-quantum cybersecurity planning into critical systems, ensuring that today's infrastructure remains secure in a quantum-enabled future.

> **“As a leader in quantum, IBM is fostering a global network of clients and partners who are already researching interesting use cases that could revolutionize industries. Energy sector applications are especially promising for grid optimization, energy trading, simulation of novel materials, and more.”**
>
> –Scott Crowder, Vice President: Quantum Adoption and Business Development, IBM

Conclusion: Preparing for a compute-driven energy future

Quantum computing is not yet a broad commercial platform, but it is no longer theoretical. The past year has solidified the trajectory of quantum technologies, elevating them to a topic of strategic consideration and placing them on course to intersect with the same large-scale forces reshaping global energy systems. From AI-driven computing demand to rising grid complexity, decarbonization efforts, and heightened concerns around security and resilience, quantum computing has an ever-growing role to play.

In the near-term, quantum's influence will be targeted rather than universal. Its early value lies in its ability to complement existing tools, with hybrid computation workflows unlocking new approaches across materials discovery, system optimization, climate modeling and infrastructure planning. Looking to the future, however, quantum begins to introduce a new operational schema with specialized data center requirements and new cybersecurity considerations that energy leaders cannot afford to ignore.

Quantum's impact will unfold over years, not quarters — but preparation must happen today. Energy leaders who understand quantum's trajectory, limitations and opportunities will be best positioned to balance risk and reward in an increasingly computing-driven energy era.

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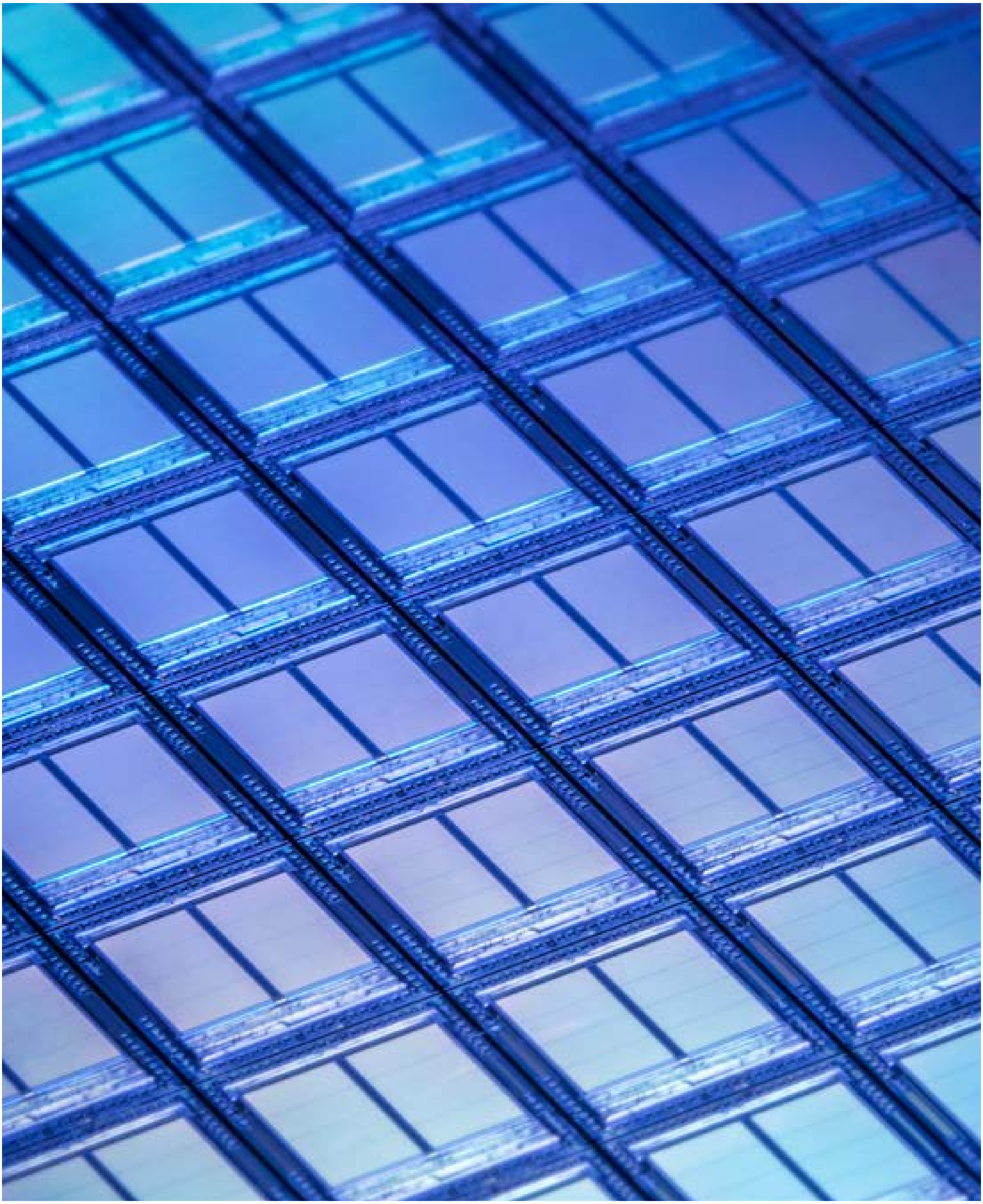

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For more information about 451 Research, please visit our website.