HBS Alumni Bulletin

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QUANTUM LEAP

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John Levy's quest to make quantum computing an accessible superpower

AGAIN AND AGAIN

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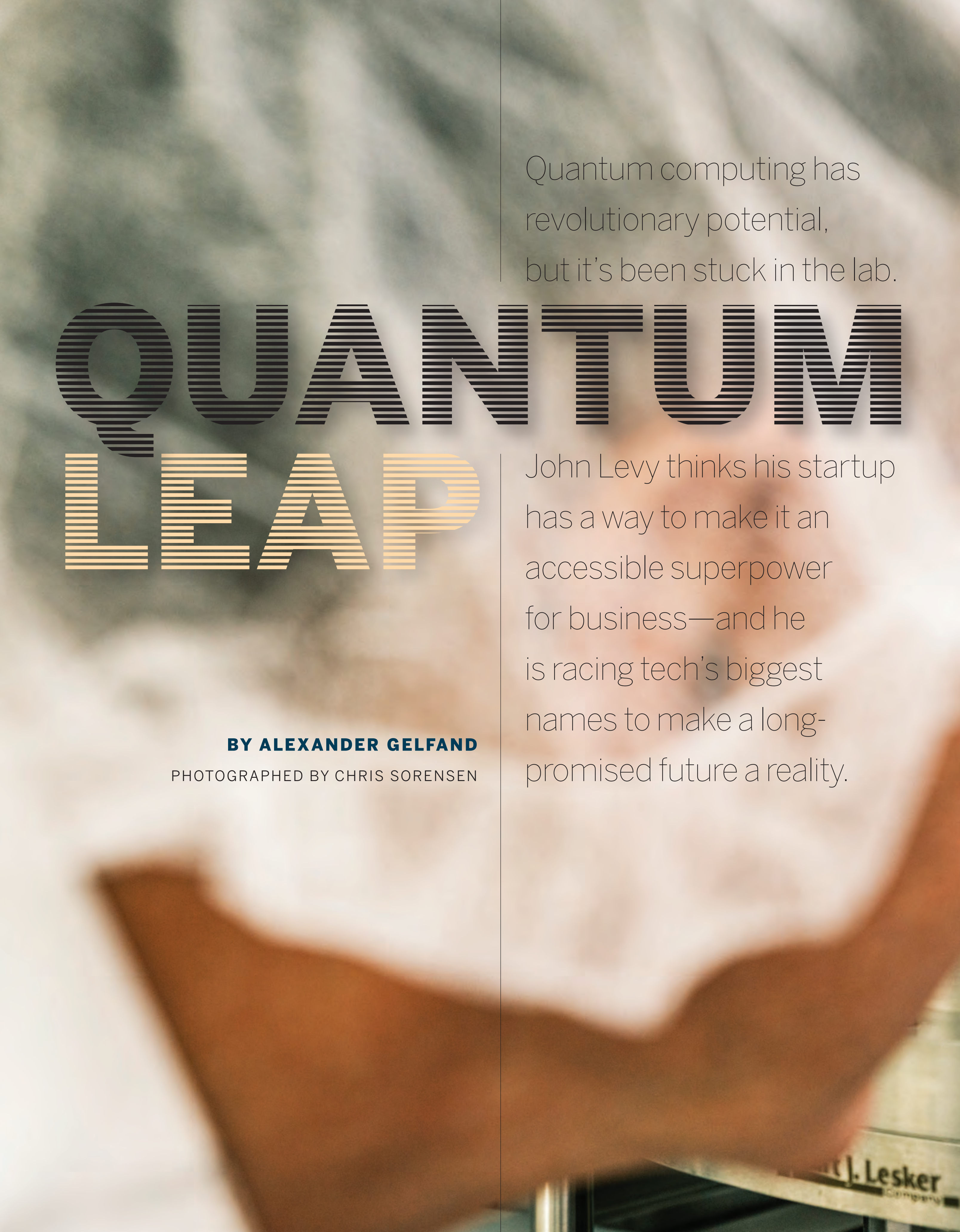
The deep power of rituals

Harvard Business School

Bright Future

This glass art hangs near the entrance to the Elmsford, New York, offices of SEEQC, a quantum computing startup founded by **John Levy (MBA 1979)**. It features “masks” that the company uses to etch its superconducting computer chips—the engines of its efforts to turn quantum computers from an experimental technology into a commercially viable tool. **See page 54.**



Quantum computing has revolutionary potential, but it's been stuck in the lab.

QUANTUM LEAP

John Levy thinks his startup has a way to make it an accessible superpower for business—and he is racing tech's biggest names to make a long-promised future a reality.

BY ALEXANDER GELFAND

PHOTOGRAPHED BY CHRIS SORENSEN

"This is the first new kind of computer in 75 years," says John Levy (MBA 1979), CEO of the quantum computing startup SEEQC. "And we're building it on a chip!"

Strolling through his company's design and testing facility in Elmsford, New York, Levy looks less like a veteran technology entrepreneur than a kid in a candy store.

A lifelong techie, Levy learned to read by deciphering *The Boys' First Book of Radio and Electronics*, a 1954 classic that gave step-by-step instructions for building a radio receiver. "I have this weird relationship with technology, and this weird kind of intuition about it," he says.

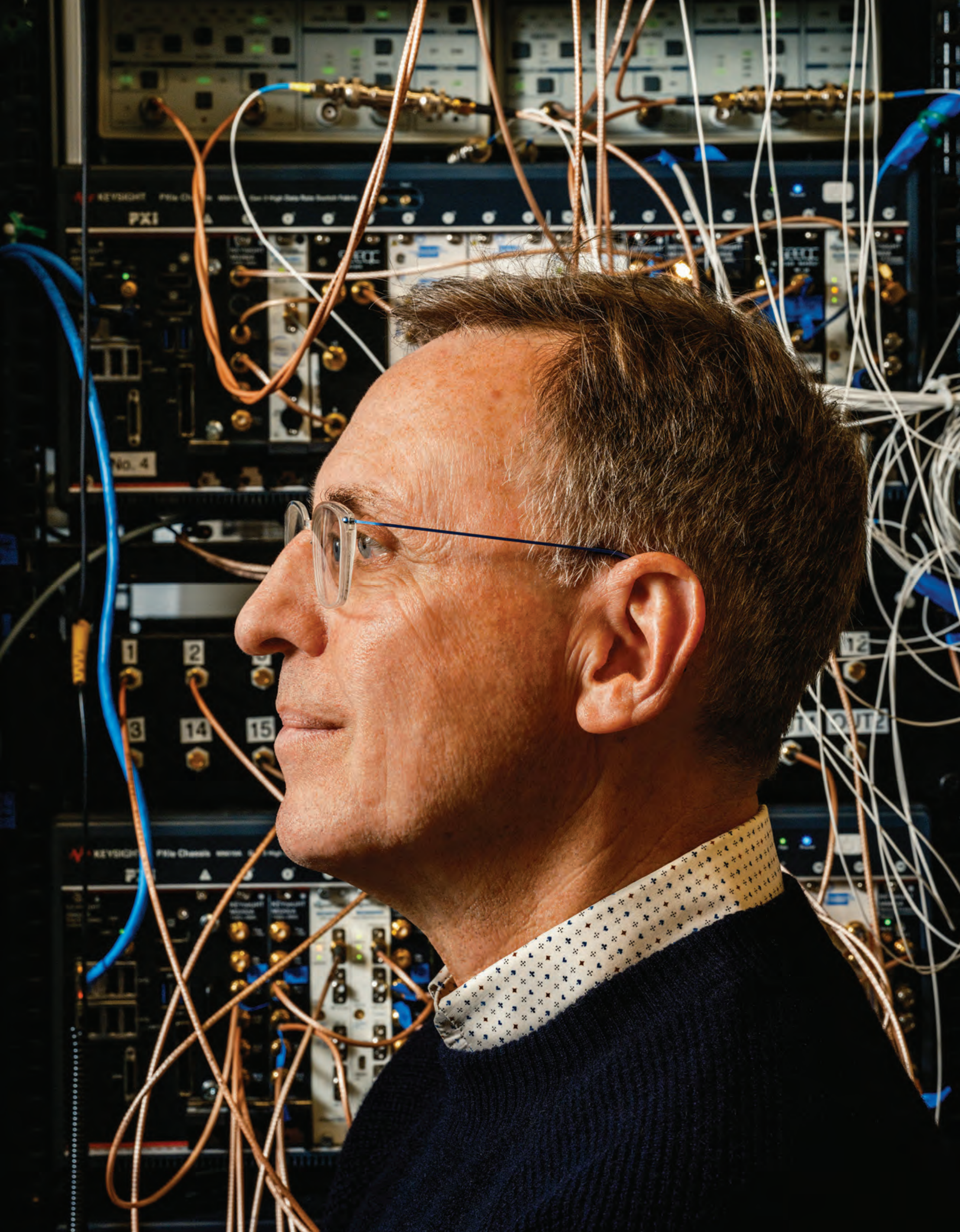
Levy's goal: Turn quantum computers from an experimental technology into a commercially viable tool.

That intuition has served him well: Over the past three decades, Levy has founded and led several tech companies and played a role as an investor and board member at dozens more. Now he and his team of scientists and engineers are trying to turn quantum computers from an experimental technology into a commercially viable, enterprise-grade tool that will be exponentially more powerful than today's digital computers.

Any sector that relies on computers for simulation, optimization, machine learning, or security—from finance to pharmaceuticals, logistics to web services—will be disrupted, with experts predicting that quantum machines will rapidly perform tasks that would take today's fastest digital supercomputers years to complete. Quantum computers will be able to carry out complex financial chores like pricing derivatives and optimizing portfolios in the blink of an eye. They will crack even the strongest digital encryption codes in seconds rather than centuries. (The day quantum computing becomes a reality is the day conventional digital security ends.) They should even be able to do things that digital computers cannot do at all, like realistically modeling molecules for more efficient drug discovery and material design.

The equipment that SEEQC—short for Scalable Energy Efficient Quantum Computing and pronounced "seek"—is using to achieve this computational dream looks like something straight out of a sci-fi film. The gleaming steel cylinders hanging from the ceiling, for example, are dilution refrigerators: cryogenic devices that cool SEEQC's quantum computing chips to between 10 and 20 millikelvins, or -469°F, a temperature at which matter behaves in ways that can only be explained by the abstruse laws of quantum mechanics and at which SEEQC's chips become fully operational.

Of particular interest to Levy, however, is the jumble of room-temperature hardware and wiring that sits next to the refrigerators and communicates with the quantum chips nestled inside them. Virtually every quantum computer in existence requires a similar mess of coaxial cables and equipment racks to function. Levy likens the setup to ENIAC, the first programmable digital computer, a room-sized behemoth that sported 18,000 vacuum tubes and resembled the unholy offspring of a fuse box and a telephone exchange when it was unveiled in 1943.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"This is the complexity you need to run five qubits," Levy says, referring to the fundamental units of information used in quantum computing. *Qubit* is shorthand for "quantum bit," a bit being the basic unit of information used in digital, or classical, computing. The equipment required to manage even 100 qubits would pack the room, floor to ceiling. SEEQC, like many other companies in the quantum-computing space—including heavyweights like IBM, Intel, and Google—is ultimately aiming for at least a million qubits.

"Imagine if you needed hundreds of thousands or even millions of coaxial cables to support a single quantum computer," says Levy. "At some point, it becomes impossible." The cumbersome room-temperature systems that support the current generation of small experimental quantum computers could never be scaled up to support commercially useful ones, much less data centers that contain thousands of them.

SEEQC is attempting to replace all that room-temperature equipment with digital control chips that measure one centimeter on a side and function at the same unimaginably low temperatures as the company's quantum processors. The latter measure only half a centimeter per side and sit directly on top of the control chips, effectively squeezing a roomful of equipment into a fingernail-sized package.

Levy acknowledges that full-blown, enterprise-grade quantum computers are still a ways off. This is hardly surprising: It took more than a decade to go from the vacuum tubes that made ENIAC hum to the transistors and integrated circuits that powered the first commercial mainframes, and decades longer to develop the kinds of chip-based systems that now power everything from smartphones to supercomputers. Some experts believe that quantum computing will follow a similar decadal timeline, which would put SEEQC and its chip-based systems right at the bleeding edge of the next computer revolution.

Plenty of challenges lie ahead. Right now, for instance, qubits are so delicate and prone to error that no one can say, with any certainty, when reliable, all-purpose quantum computers will become a reality. And the competition to bring the first working solution to market is incredibly fierce.

Levy is aware of all this. "We're little guys," he says, laughing. "We're going against the biggest, best-funded companies in the world. We know that." But if any of that worries him, he doesn't show it. He's confident that his team has the skills and expertise to execute SEEQC's roadmap. He is also convinced that the technology they're developing is absolutely necessary to turning today's primitive quantum computers into something that businesses can actually use.

Just a few years ago,

it would have been easy to dismiss Levy's vision as mere wishful thinking. First proposed in the early 1980s by the theoretical physicist Richard Feynman, quantum computing represents an entirely novel approach to computation. But the same fundamental physical properties that make it transformative also make it fiendishly difficult to implement—and almost impossible for anyone but professional physicists to fully understand.

The bits that classical computers use to store data and perform calculations have only two possible states: 0 or 1. But the laws of quantum mechanics, which govern the world of atomic and subatomic particles, are inherently probabilistic. Until the state of a qubit is measured, it is neither 0 nor 1, but rather some distribution of probabilities that it could be either, all existing simultaneously. This principle, known as superposition, inspired the Austrian physicist Erwin Schrödinger to imagine his famous cat, which was both alive and dead at the same time. The state of one qubit can also affect the state of another even though the two are physically separate—a phenomenon called entanglement, which Albert Einstein referred to as "spooky action at a distance." Thanks to these bizarre properties, quantum computers can solve problems that lie beyond the reach of classical ones.

"Computationally, it's like our generation's discovery of fire," says **Carolyn Fu**, an assistant professor of business administration who studies innovation strategy at HBS. "It's going to change the way we live our lives. We just don't know how."

After decades of false starts and incremental advances, quantum computing finally began to show signs of business relevance about 10 years ago. In 2016, IBM made a quantum processor available for the first time via the cloud. Not long thereafter, Microsoft introduced a new programming language designed specifically for quantum computing. (In addition to novel hardware, quantum computers require new software to exploit their unique capabilities.)

Since then, progress has accelerated rapidly, and interest in quantum computing has exploded. **Amit Kumar (MBA 2008)**, a managing director and senior partner at Boston Consulting Group, estimates that more than 300 companies are currently active in the quantum space and that more than $3 billion in investment has poured into the sector globally over the past few years.

"There's a lot of money going into the ecosystem," Kumar says. That influx is being driven by the expectation that quantum computers will prove vastly superior to classical computers at complex, resource-intensive

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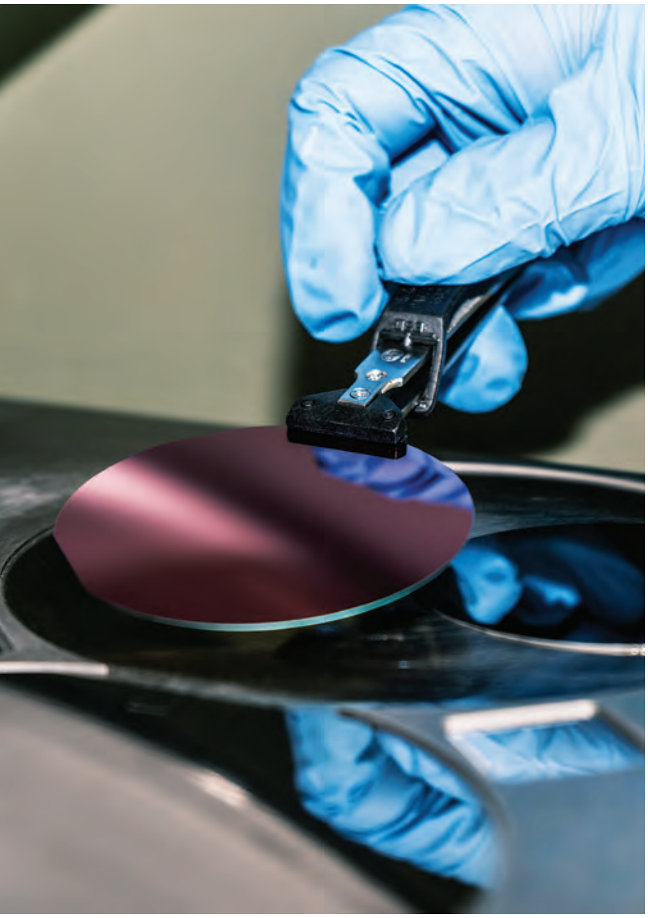
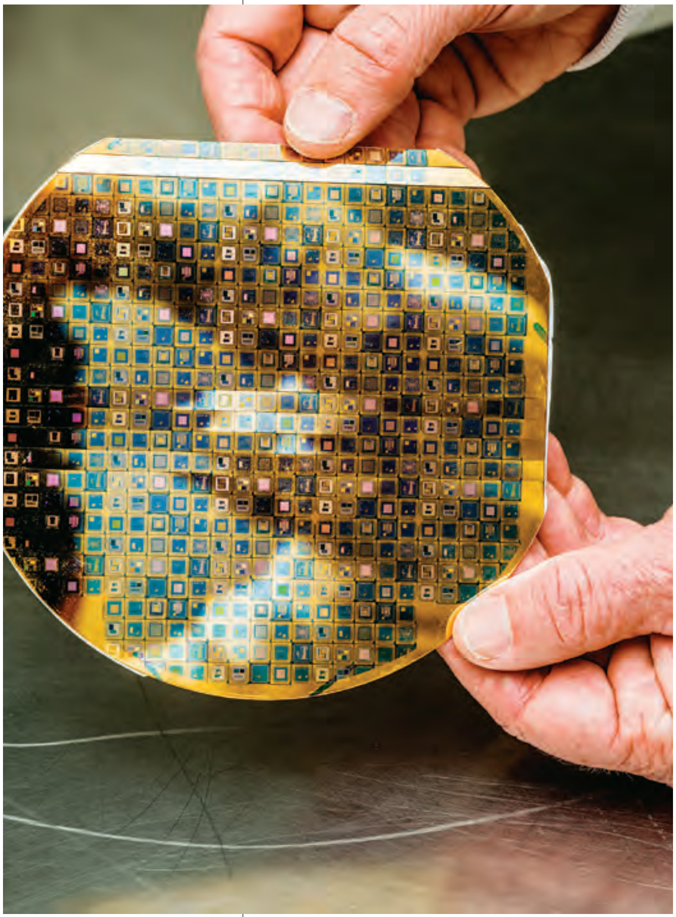



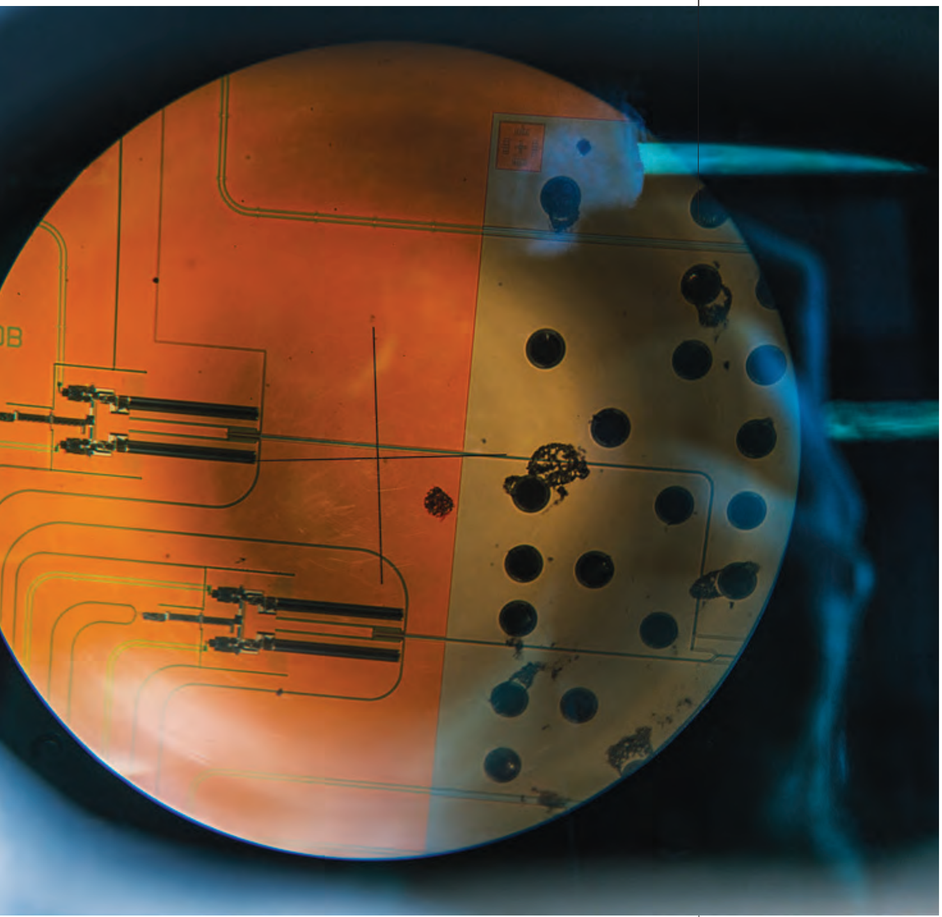

tasks like training AI systems, optimizing supply chains, or designing airplanes and automobiles. According to Kumar, many financial services firms are already exploring the prospect of using quantum computers to estimate portfolio risk—something that classical computers struggle to do in a timely fashion.

Quantum computers also should excel at modeling molecules and their interactions with one another, making it far easier to do everything from discovering new medicines to designing better batteries. The pharmaceutical and chemical industries have taken note: The venture capital arm of the pharma giant Merck, for instance, invested $5 million in SEEQC's Series A round, where it was joined by the South Korean chemical company LG Chem, which produces everything from drugs to EV batteries; and BASF, the world's largest chemical manufacturer, recently joined a SEEQC-led consortium to explore how quantum computing could help simulate chemical reactions.

All that quantum magic will generate a lot of value: Kumar and his colleagues predict that by 2035, the technology will unlock $450 billion to $850 billion in combined revenue and cost savings.

Unfortunately, the quantum phenomena that make all this possible are incredibly fragile. The slightest bit of noise—a stray radio wave, an iota of heat—will cause a qubit to tumble out of its quantum state. Even swaddled under multiple layers of shielding and insulation, the qubits contained within SEEQC's quantum chips collapse within microseconds. The room-temperature hardware currently used to manage qubits is inherently noisy, generating both heat and interference. Sending signals back and forth between ultra-cold and room-temperature environments also causes delays, or latency, which further degrades performance. Error correction, which involves catching and fixing the random mistakes that inevitably crop up in any computer, is also a challenge, as quantum error correction requires adding more qubits—and that means yet more noisy control equipment. The whole situation is so messy and unstable that industry insiders call this the noisy intermediate–scale quantum (NISQ) era.

Various companies are experimenting with other kinds of qubits that have longer lifespans and different hardware requirements, but that too presents business risk: No one knows which flavor of qubit will prevail, so coordinating technology development—and figuring out where to invest—is tricky. Fu compares the situation to the early days of the semiconductor industry, when companies competed to see how classical computers could be used and what hardware might best support them. That kind of uncertainty poses a challenge for investors and tech companies alike, as whoever first develops a winning solution is likely to dominate the market—and everyone else will struggle to keep up. "Venture capitalists and private investors will lose a lot of money if they bet on a technology that doesn't get to market first," Kumar says.



Levy and his team estimate that the infrastructure required to maintain a single qubit currently costs between $8,500 and $15,000, while their chip-based system should drive that cost below $1,000.

Levy argues that SEEQC's approach won't just solve the noisy hardware problem; it will also mitigate the lack of certainty concerning qubits themselves. That's because SEEQC's control chips are inherently qubit-agnostic: While they currently support the company's own superconducting qubits, they should work with all the other varieties of qubit under development. "That's part of the beauty of our business model," Levy says. "We're trying to decouple ourselves from a lot of the vagaries of the industry that we can't really control." As a result, SEEQC could take some of the uncertainty out of a sector whose core technology relies on the Heisenberg uncertainty principle. Indeed, if Levy succeeds, the company might wind up supplying the technology that closes the door on the NISQ era once and for all.

"This," Levy says, a conspiratorial twinkle in his eye, "is the black art of chipmaking."

Standing in the heart of SEEQC's chip foundry, Levy is surrounded by the equipment and materials required to manufacture superconducting microchips: There are industrial lasers, machines that can deposit a layer of gas one atom thick, and rare earth elements like niobium and tantalum waiting to be etched into circuits. ("I don't know what he's doing in there," Levy says, peering at a figure in a clean-room suit hunched over a laboratory fume hood. "But something!") Not many startups have their own in-house chip manufacturing facilities, much less the technical expertise to produce their own cryogenic quantum processors. But not many have SEEQC's pedigree, either.

The startup emerged from Hypres, a company that was established in Elmsford in 1983 by refugees from IBM's superconducting electronics division, and which was chaired until 2012 by veteran venture capitalist **Pitch Johnson (MBA 1952)**. Hypres's scientists and engineers, many of whom hailed from the former Soviet Union, pioneered a low-temperature superconducting technology that was faster, more energy-efficient, and less noisy than conventional digital circuitry. Much of the firm's work has since involved supplying cryogenic superconducting radio-frequency communications systems to the US government for classified intelligence purposes.

Soon after Levy joined the board of Hypres in 2010, however, his intuition told him that the most fruitful application of its technology lay in computation. After succeeding Johnson as board chairman in 2012, Levy helped steer the company into the federally funded Cryogenic Computing Complexity (C3) initiative, which aimed to develop energy-efficient superconducting supercomputers.

At first, Levy envisioned developing superconducting servers that could speed up data center operations while reducing power consumption. But he dropped that idea when he realized that Hypres could instead apply its superconducting know-how to quantum computing, which was finally beginning to gain traction. By 2017, Hypres had launched SEEQC as a wholly owned subsidiary. In 2019, the company spun out as an independent entity.

Today, SEEQC has 32 employees sprinkled across offices in Elmsford, London, and Naples, Italy, and Levy's initial intuition seems to be paying off. In 2023, the company rolled out a first-generation quantum computer, SEEQC Red, which used conventional room-temperature control equipment to establish a baseline against which to compare its digital chip-based systems. In 2024, it introduced SEEQC Orange, which Levy described as "the world's first quantum computer controlled by a digital chip at superconducting temperature," albeit one with limited functionality, and it plans to unveil another upgraded model by the end of the year.

Along with all their other advantages, SEEQC's digital control chips should also make quantum computing more affordable: Levy and his team estimate that the infrastructure required to maintain a single qubit currently costs between $8,500 and $15,000, while their chip-based system should drive that cost below $1,000.

Businesses that stand to gain from quantum computing are paying attention. In addition to BASF, Merck, and LG, the chip manufacturer NVIDIA, which produces the digital GPUs that power AI systems, is working with SEEQC to integrate the startup's quantum chips into its machine learning platforms. Applying quantum computation to machine learning—a phenomenon known as "quantum AI"—would allow artificially intelligent systems to process vast amounts of data at incredible speed, enabling businesses to train their AI models more quickly and energy efficiently, and to generate deeper insights from them.

SEEQC will not be delivering a full-blown, enterprise-grade quantum computer anytime soon. Levy believes the company will be able to build at least some basic error correction into its chips by 2025, for instance, but he carefully avoids predicting when more robust error correction will be possible, or when the company will be able to begin ramping up from a handful of qubits to thousands of them or more.

Nonetheless, sitting in a meeting room back at the design and testing facility, scrolling through charts and graphs that illustrate the technical superiority of SEEQC's control chips, Levy practically brims with enthusiasm: He has no doubt that the firm can corner the chip-based quantum computing market, so long as he and his team continue to hit the milestones on their roadmap, just as they have for the past several years.

"I can see the path," he says. "I can see it all."

"The race really is about who can come to the market first with real use-cases and real applications," says Levy.

Notwithstanding

Levy's confidence, the road ahead will not be easy.

Although SEEQC has already raised $38 million and is gearing up to raise another $50 million, those figures pale in comparison with what its largest competitors have been able to pour into quantum computing. While precise numbers are hard to come by, Kumar figures that IBM alone has probably invested billions so far, and Google has announced that it intends to spend billions more to develop an error-free quantum computer by 2029. In addition, venture capital can be difficult to secure, in part because many VCs lack the technical expertise to properly vet the startup. "The groups that can diligence what we're doing tend to be corporate venture funds that have quantum scientists on staff," Levy says—like Merck's M Ventures fund, which has access to an in-house quantum computing task force.

The technical challenges, meanwhile, are even thornier, and they affect the entire sector. While everyone agrees that a quantum computer that can handle any algorithm and run indefinitely without crashing is years away, no one knows exactly how many. Kumar thinks companies may be able to begin building quantum computing into their operations within 3 to 5 years, and that fully reliable, all-purpose quantum computers may be 10 or more years away; but only time will tell. "The race really is about who can come to the market first with real use-cases and real applications," he says.

The race metaphor applies to any company that is trying to develop a useful quantum computer. But it also applies to any business that could gain a competitive advantage by adopting quantum computation—or lose their edge by failing to jump on the technology early enough. As a result, companies that deal with the sort of complex use-cases that could benefit from quantum computation should begin playing with the technology now, Kumar advises.

From Levy's perspective, that kind of experimentation helps everyone: Aspiring quantum consumers, for example, gain insight into when the technology will be ready for prime time, and what it will be able to do when it is, while aspiring providers like SEEQC and its rivals get to learn about what large companies want and need. The clearer everyone is about what enterprise-grade quantum computing will be able to do for business, the more everyone stands to profit when it finally arrives.

"We're interested in the community as a whole being able to solve real problems, because that drives demand for quantum computers," says Levy. "And we care about driving demand for quantum computers because the more there are, the more chips they're going to want to buy."