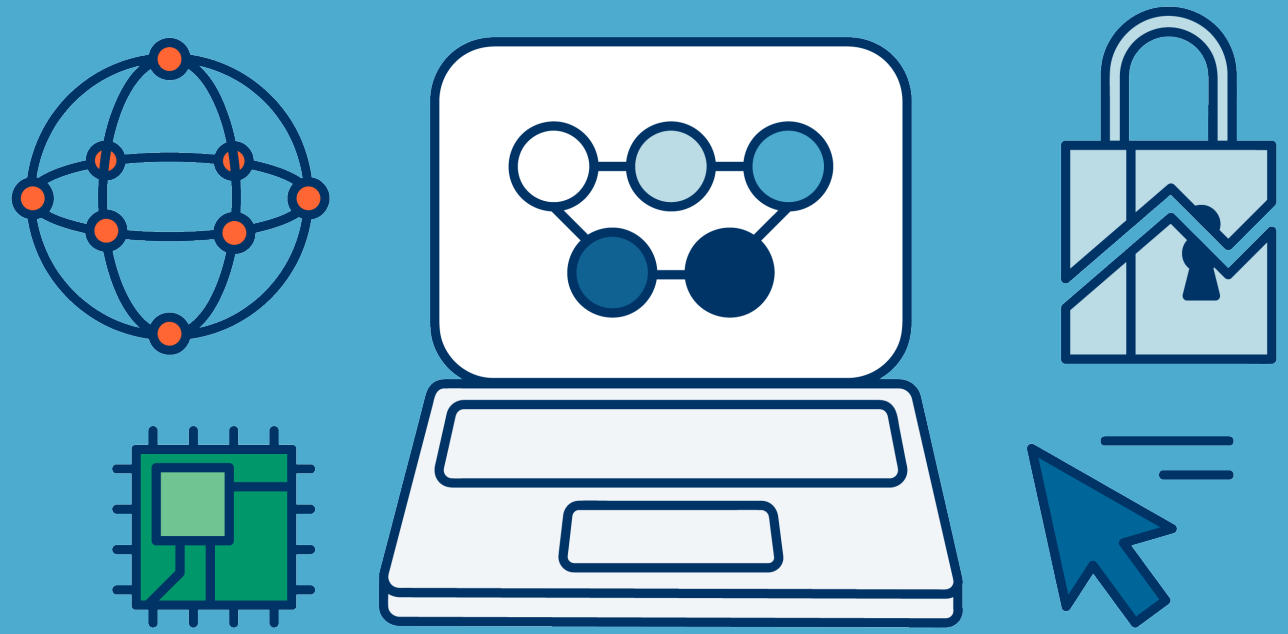

The Big Tech In Quantum Report:

How Google, Microsoft, Amazon, IBM, & Intel Are Battling For The Future Of Computing

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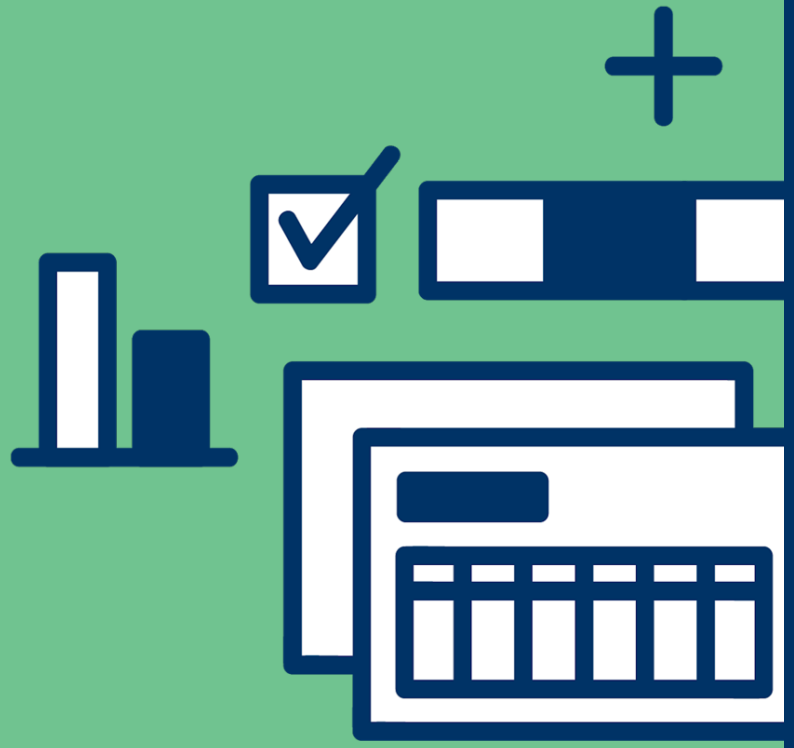

WHAT IS CB INSIGHTS?

CB Insights helps the world's leading companies make smarter technology decisions with data, not opinion.

Our Technology Insights Platform provides companies with comprehensive data, expert insights and work management tools to drive growth and improve operations with technology.

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CB Insights helps us compress our time-to-decision when gathering and analyzing data and getting an external view on what's happening in the market so we can quickly take action.

Meraj Mohammad
Vice President, Ventures Group, ADP

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What Is Quantum Computing? Definition, Industry Trends, & Benefits Explained

Post-Quantum Cryptography: A Look At How To Withstand Quantum Computer Cyber Attacks

Is Quantum Computing The Next Banking Arms Race?

How Quantum Tech Could Change Drug Discovery, Diagnostics, And Patient Privacy

75+ Quantum Tech Companies That Could Impact Healthcare, Finance, Cybersecurity, And More

How Quantum Computing Will Transform These 9 Industries

Quantum Computing Vs. Classical Computing In One Graphic

The Big Tech In Pharma Report: How Amazon, Microsoft, Apple, And Google Are Capitalizing On The Digital Transformation

The Big Tech In Healthcare Report: How Facebook, Apple, Microsoft, Google, & Amazon Are Battling For The $8.3T Market

The Big Tech In Fintech Report: How Facebook, Apple, Google, & Amazon Are Battling For The $28.2T Market

How The $100B+ Creator Economy Is Going To Be Shaped By Big Tech

25 Business Moats That Helped Shape The World's Most Massive Companies

Contents

Summary Of Findings

Overview of big tech's activities in quantum

Big tech's quantum activity is ramping up quickly

- Google, Microsoft, Amazon, IBM, and Intel are all developing their own quantum computing hardware. Big tech companies have been behind several breakthroughs in the space.
- In July 2021, Microsoft's venture arm took part in a $450M round to PsiQuantum — the most well-funded quantum computing startup in the world.

Cloud is a key area of quantum competition for big tech

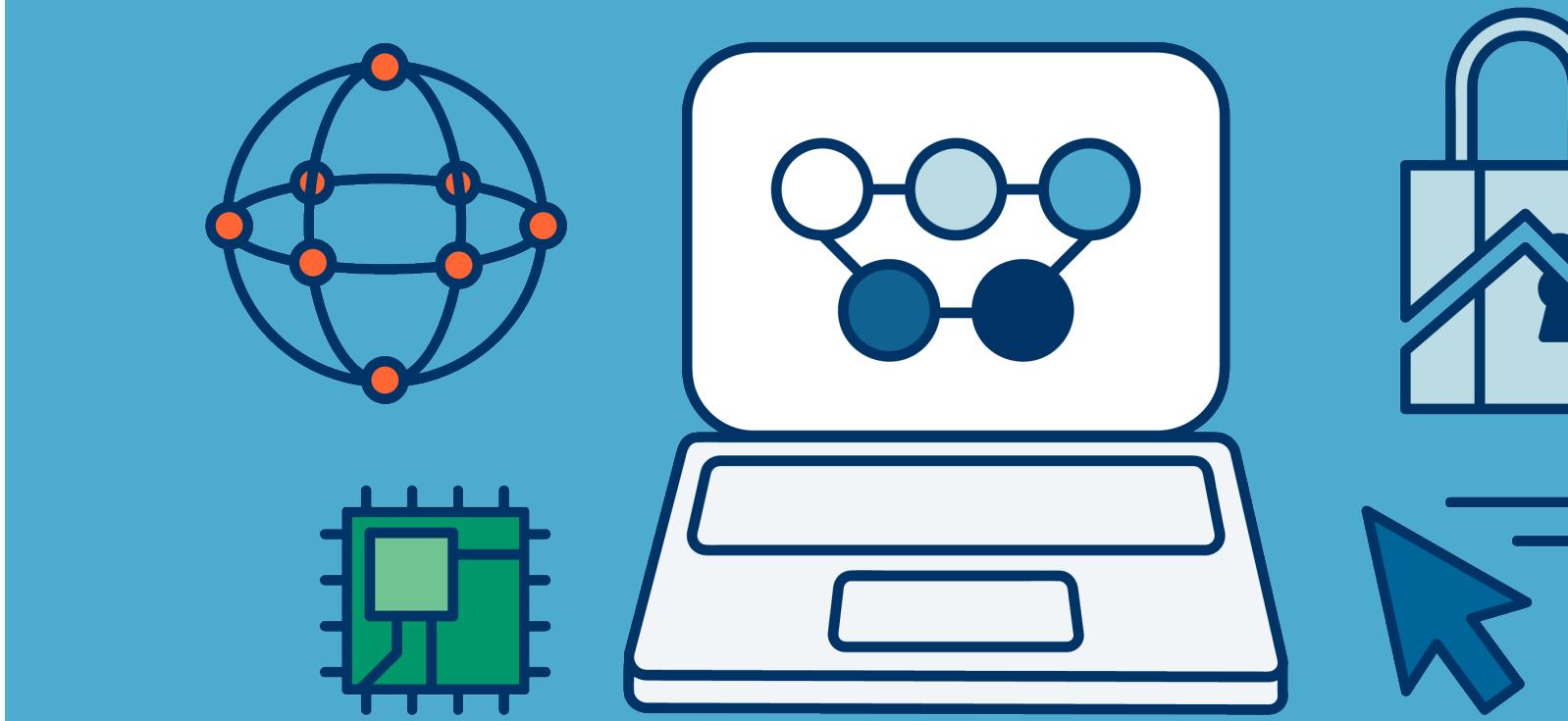
- Google, Microsoft, Amazon, and IBM have all launched quantum computing services on their cloud platforms. Startups have partnered with big tech companies to offer remote access to a broad range of quantum computers.

What's next?

- **Big tech forges ahead with quantum advances.** Google, Microsoft, Amazon, IBM, and Intel all have ambitious quantum roadmaps. Expect rising qubit counts and more frequent demonstrations of commercial applications.
- **Watch for quantum computing to become a hot geopolitical issue, especially for US-China relations.** Expect big tech companies, including China-based Baidu and Alibaba, to be drawn deeper into political debates. In the US, government efforts to rein in big tech could be countered by officials nervous about keeping up with countries racing ahead with quantum technology.
- **Other big tech players could join the fray.** Facebook and Apple have not announced quantum tech initiatives, but both will be monitoring the space and have business lines that could benefit from quantum computing.

To find out more about what quantum computers are, how they work, and why qubits matter, check out our explainer.

Where Big Tech Is Making Moves



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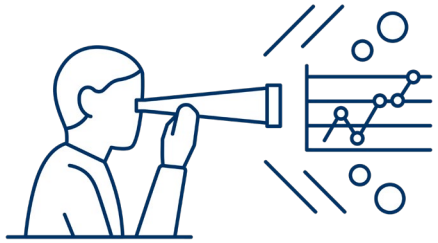
How big tech is reshaping quantum computing

Google	Google is building advanced quantum computing hardware, has a focus on developing quantum AI, and is putting energy into achieving scientific breakthroughs around quantum. Alphabet also has a secretive non-Google team working on quantum tech. Expect Google to look to gain an edge by integrating quantum-powered AI capabilities throughout its product ecosystem.
Microsoft	Microsoft offers access to quantum computers from numerous makers on its Azure cloud platform. The company is also pursuing its own quantum hardware and its venture arm has invested in PsiQuantum, the most well-funded quantum computing startup in the world. Microsoft's quantum positioning signals that it is doubling down on serving enterprises.
amazon	Amazon has launched a quantum cloud service on AWS by partnering with quantum computing startups. The company has also made recent moves to develop its own quantum hardware. Amazon's business lines across e-commerce, logistics, healthcare, and more could be set for a quantum boost. Securing a lead in quantum computing could also be key to fending off quantum-forward rivals in the future.
IBM	IBM is investing heavily in developing quantum computing hardware. It is the leader for quantum computing patents and has an ambitious roadmap to scale up the power of its machines. The company has also partnered extensively with top enterprises on quantum projects. A pioneer in making classical computing useful for corporations, IBM is hoping that history will repeat itself with quantum.
intel	Intel is developing its own silicon-based quantum computing hardware. The company hopes that it can quickly scale this approach using well-established methods from the semiconductor industry. Intel also has a strong focus on post-quantum cryptography — encryption methods that protect against the looming threat from quantum computers — and is already beginning to secure its ecosystem of products.

MARKET DRIVERS

What's driving big tech activity in quantum computing?

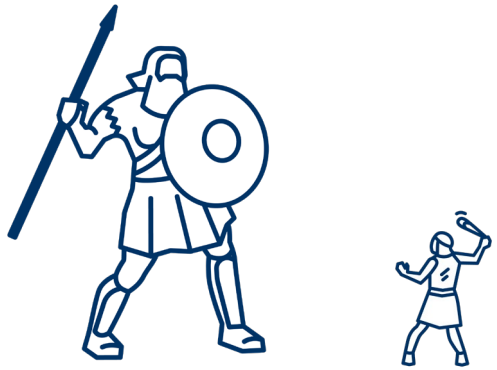


Quantum FOMO — a revolution in computing is in the cards

Any company that can quickly scale up quantum computing will find itself with a dramatic advantage across far-reaching areas like optimization, simulations, and AI. While formidable challenges remain, big tech players don't want to miss out.

An opportunity to leapfrog into new markets

Powerful quantum computers could be game-changing for industries like banking, drug discovery, logistics, and many more. Becoming a quantum computing leader could allow big tech giants to compete in new markets and become vital partners for an array of incumbents.



Defending key business lines

Big tech is sprawling and competes across countless verticals. If big tech companies lag on quantum, then quantum computer-equipped rivals could weaken big tech's grip on areas like AI, e-commerce, cloud services, and more.

Quantum computers could change tech forever

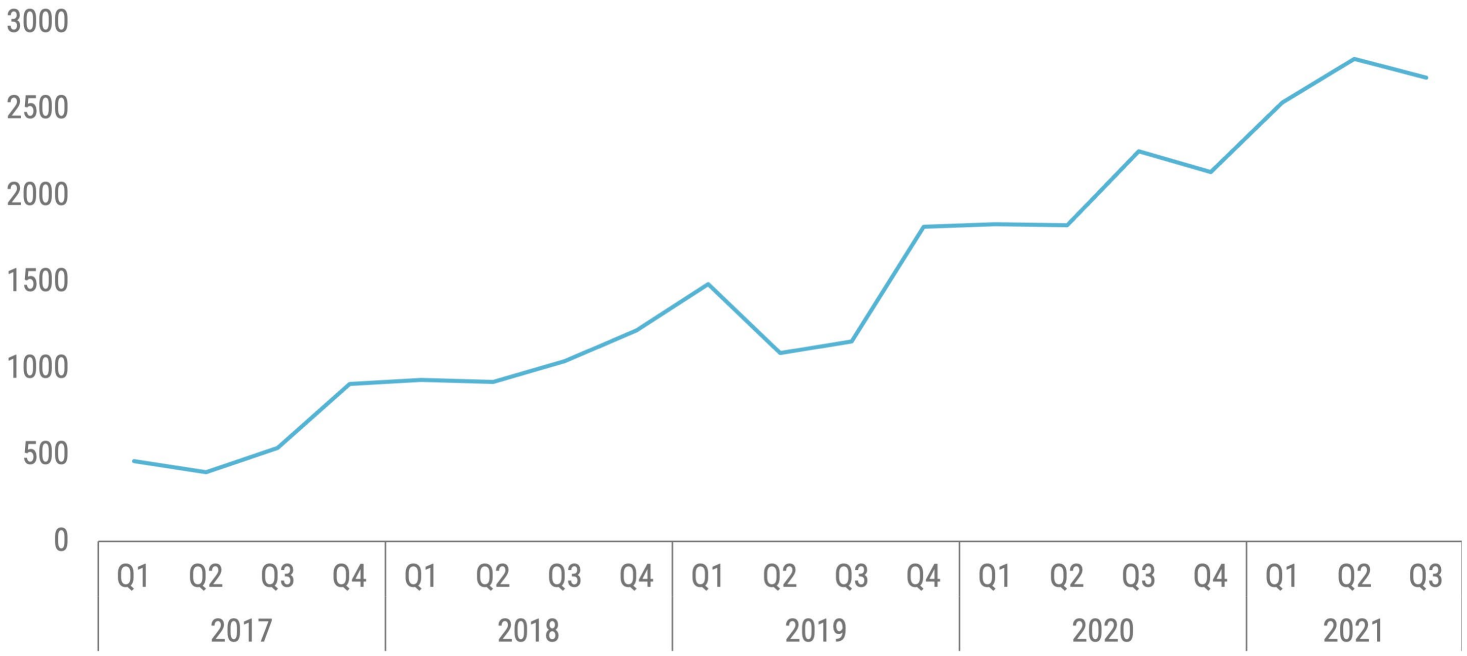
The quantum computing industry is still nascent and faces countless scientific and engineering challenges — but the pay-off could be huge.

Quantum computing allows a new approach to processing information that could speed up certain tasks millions of times over and open new algorithmic possibilities.

Even though it is early days, big tech companies reckon that the risk of falling behind on quantum is greater than the potential for wasted efforts.

Quantum computing interest continues to climb

Media mentions related to quantum computing, Q1'17 – Q3'21



Source: cbinsights.com

CBINSIGHTS

Quantum prowess will extend big tech's reach

In the future, quantum computers could be money spinners across a broad array of industries.

BCG estimates that quantum optimization applications in finance, logistics, and aerospace alone could generate up to $220B in annual revenue once the tech matures.

Big tech will want to capitalize on this quantum advantage by building products for previously inaccessible markets and becoming vital partners to industry incumbents.

	Applications	Value creation potential[1] ($B)	
		Low	High
Cryptography ($40-$80B)	Encryption/decryption	$40	$80
Optimization ($100-$220B)	Aerospace: Flight route optimization	$20	$50
	Finance: Portfolio optimization	$20	$50
	Finance: Risk management	$10	$20
	Logistics: Vehicle routing/network optimization	$50	$100
Machine learning ($150-$220B)	Automotive: Automated vehicle, AI algorithms	$0	$10
	Finance: Fraud and money-laundering prevention	$20	$30
	High tech: Search and ads optimization	$50	$100
	Other: Varied AI applications	$80+	$80+
Simulation ($160-$330B)	Aerospace: Computational fluid dynamics	$10	$20
	Aerospace: Materials development	$10	$20
	Automotive: Computational fluid dynamics	$0	$10
	Automotive: Materials and structural design	$10	$15
	Chemistry: Catalyst and enzyme design	$20	$50
	Energy: Solar conversion	$10	$30
	Finance: Market simulation (e.g. derivatives pricing)	$20	$35
	High tech: Battery design	$20	$40
	Manufacturing: Materials design	$20	$30
	Pharma: Drug discovery and development	$40	$80

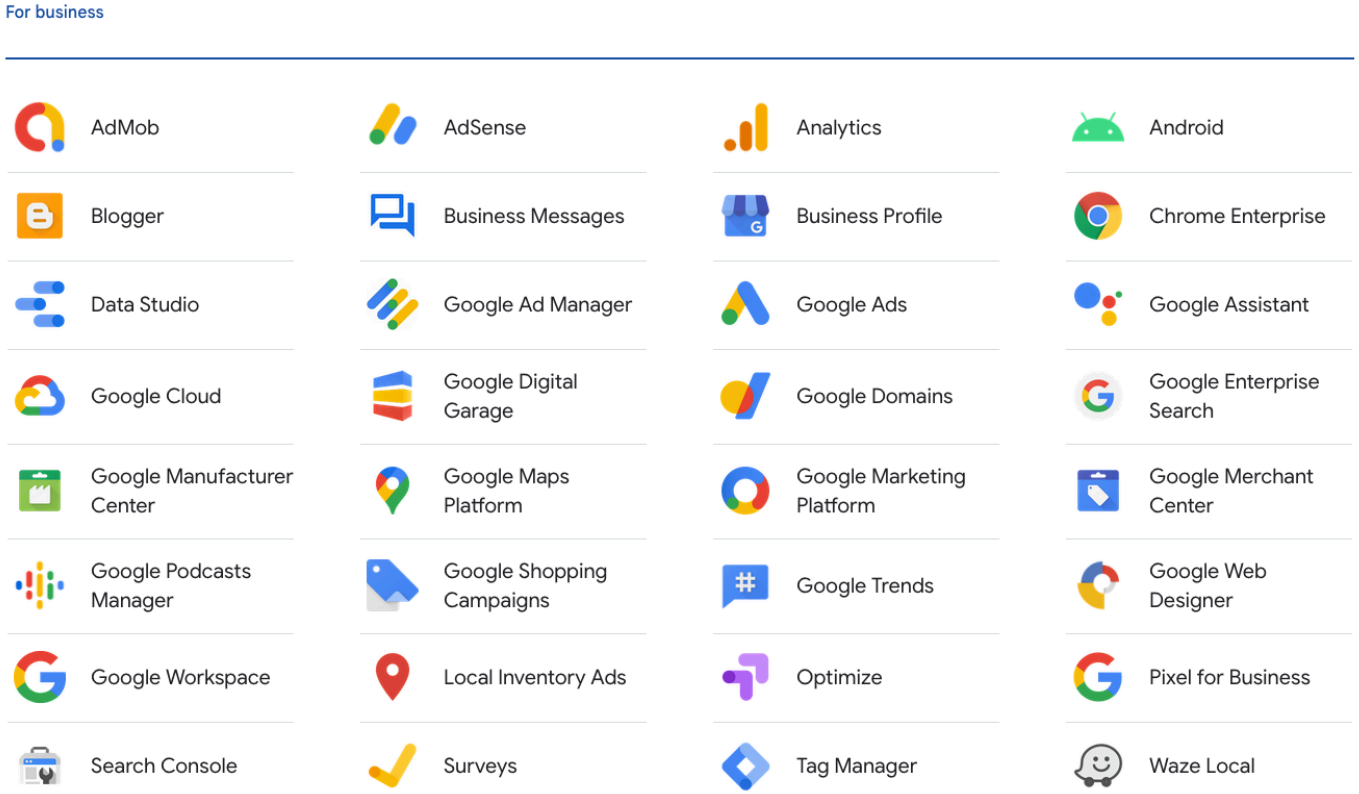
Source: BCG

Big tech will use quantum computing to shore up key products

Just as quantum computing could create opportunities for big tech to enter new markets, it also creates the potential for rivals to target services where big tech is currently dominant.

Big tech companies are wise to this and are likely already planning how to integrate quantum computing across product lines.

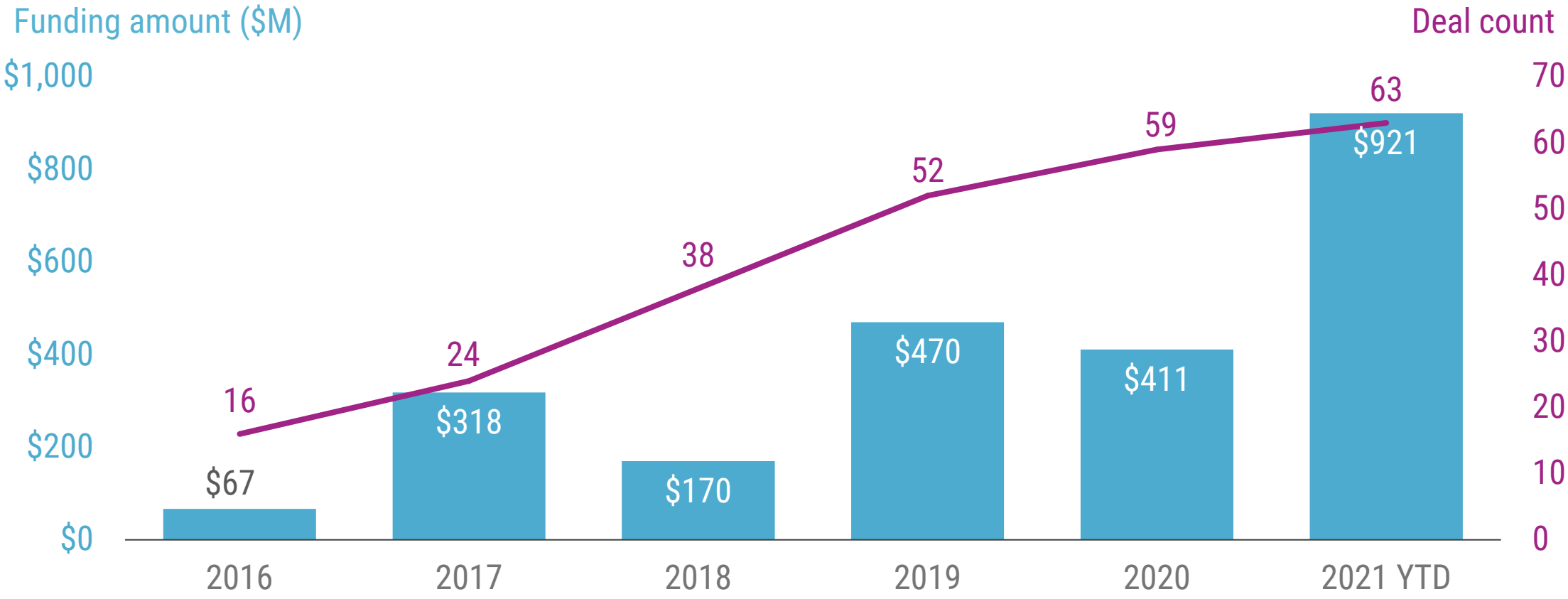
Google, for example, could eventually use quantum computing to improve products as diverse as search, ads, Google Assistant, maps, Data Studio, and more.



 Source: Google

Quantum tech funding surges in 2021…

Disclosed deals & equity funding, 2016 – 2021 YTD (12/15/21)

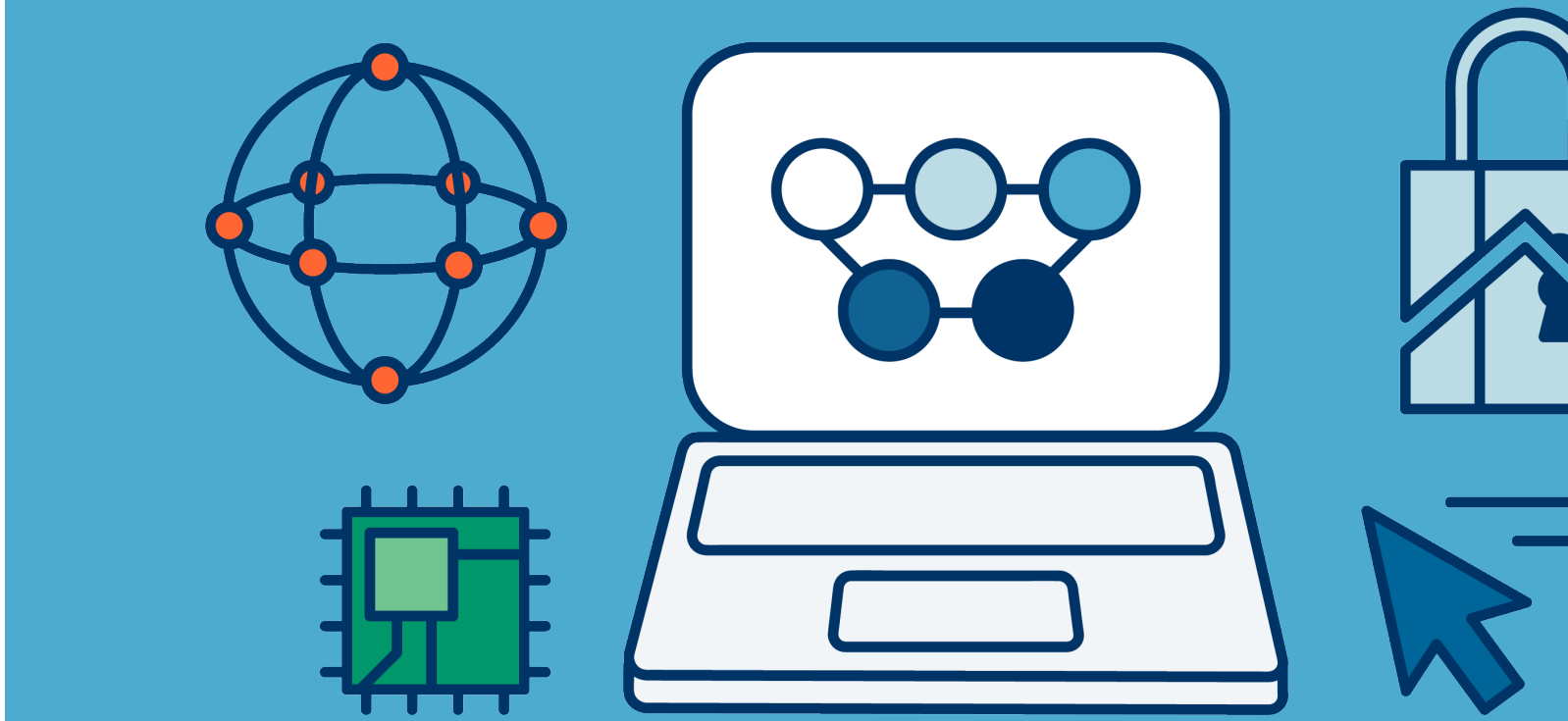


Source: CB Insights. Excludes funding from SPAC deals.

…But only a few startups have big tech backing

Company	Deal date // Amount raised ($M)	Total disclosed funding ($M)	Select investors	Description
PsiQuantum	Jul '21 // $450M	$729M	**Microsoft**	PsiQuantum is working to build a quantum computer using silicon photonic technology.
Cambridge Quantum	Dec '20 // $45M	$95M	**IBM**, Honeywell	Cambridge Quantum Computing works on developing software for quantum computers. It merged with Honeywell's quantum business in June 2021.
PsiQuantum	Nov '19 // $215M	$729M	**Microsoft**	PsiQuantum is working to build a quantum computer using silicon photonic technology.
IONQ	Oct '19 //$55M	$84M	**Google**, **Amazon**, Hewlett Packard, Samsung, Airbus	IonQ builds quantum computers using ion trap technology. It went public via a SPAC merger in October 2021.
IONQ	Jul '17 // $20M	$84M	**Google**, **Amazon**	IonQ builds quantum computers using ion trap technology. It went public via a SPAC merger in October 2021.

Google



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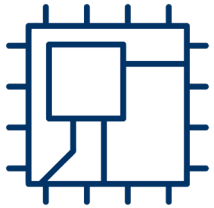
WHERE GOOGLE IS FOCUSING

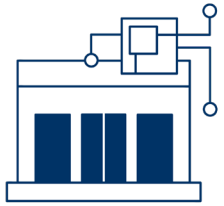


THEME 1

Google is building cutting-edge quantum computing hardware, with the aim of developing a powerful, commercially useful computer by the end of the decade

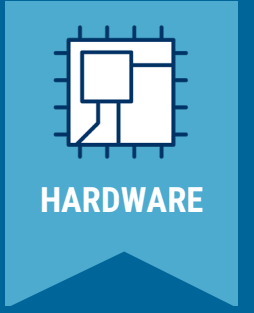
THEME 2

The search giant has made early quantum breakthroughs, including the world's first claim of "quantum supremacy"



THEME 3

Google could benefit from a quantum AI ripple effect through its core businesses



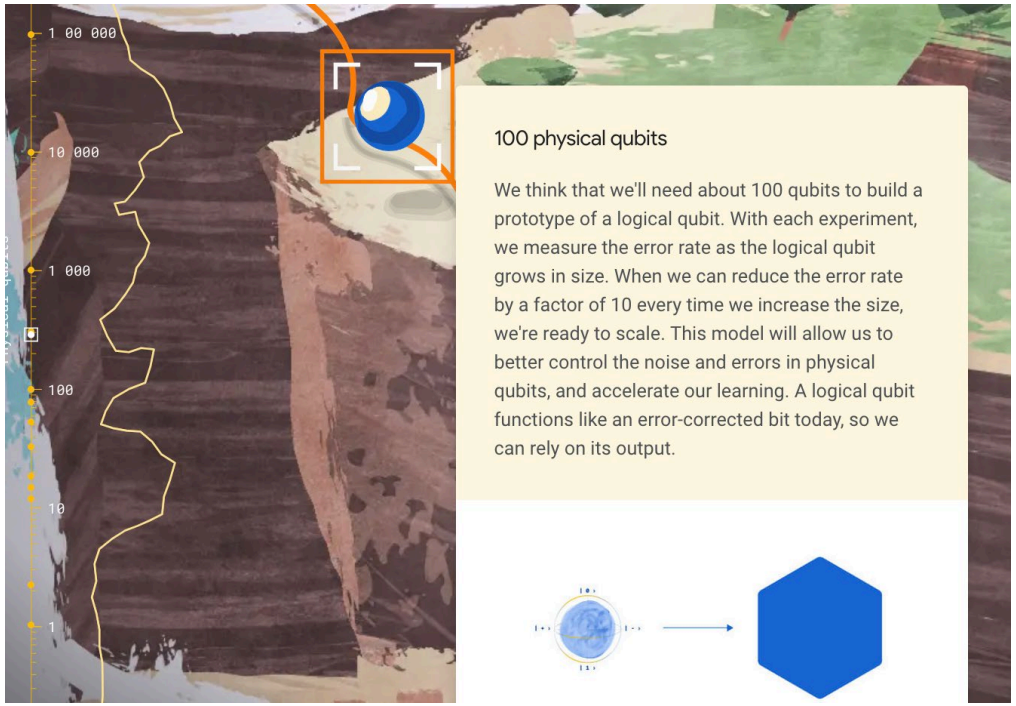
Theme 1: Google is building cutting-edge quantum technology

Google targets 1M qubits by the end of the decade

Google builds its own quantum computers, and its machines are currently among the most powerful in the world — though not yet capable enough for useful commercial applications.

Google is planning to up the number of qubits (what quantum computers use to calculate things — the more the better) to 1M by the end of the decade. The company believes this will be enough to run an error-corrected, commercially relevant quantum computer.

Google doesn't envision its quantum roadmap as an easy journey



 Source: Google

Google just opened a quantum computing campus

Google has built a quantum AI campus and data center in Santa Barbara, California to house its main quantum computing efforts.

This indicates that it is doubling down on its quantum computing bets and is expecting the tech to become a more significant part of its business.

Google is scaling up its quantum operations

Source: Google

Alphabet has a secret, non-Google quantum effort

Alphabet has a software-focused quantum team called Sandbox that is dedicated to applying quantum technology to near-term enterprise use cases. Sandbox operates mostly in stealth mode; however, recent job postings and past comments from its leadership indicate that its work includes:

- **Quantum sensors** — There are hints that Sandbox is working on a hypersensitive magnetism-based diagnostic imaging platform, possibly an MEG* system for reading brain activity, that combines quantum-based sensitivity gains (tens of thousands of times more sensitive than typical approaches) with quantum machine learning to disentangle a signal from background noise to boost sensitivity. This could allow for more precise scans or for cheaper, more flexible deployments of magnetic-based imaging devices for use beyond hospital settings, as well as improved access in lower-income countries.
- **Post-quantum cryptography (PQC)** — Quantum computers threaten much of the encryption used on the internet. Post-quantum cryptography will defend against this. Expect Sandbox's work to be focused on helping enterprises transition to PQC and making Alphabet's sprawling online services quantum-safe.
- **Distributed computing** — This tech allows computers to coordinate processing power and work together on problems. Sandbox's work here may focus on integrating near-term quantum computers into distributed computing networks to boost overall capabilities. Another approach would be to use quantum optimization algorithms to help manage distributed networks more efficiently.

*MEG stands for magnetoencephalography.

SCIENCE

Theme 2: Google has made scientific breakthroughs

Google establishes itself as a quantum science leader

Hello quantum world! Google publishes landmark quantum supremacy claim

October 23, 2019 | nature

Why Google's Quantum Supremacy Milestone Matters

October 30, 2019 | The New York Times

Google performed the first quantum simulation of a chemical reaction

August 27, 2020 | NewScientist

First 'Time Crystal' Built Using Google's Quantum Computer

July 30, 2021 | Quantamagazine

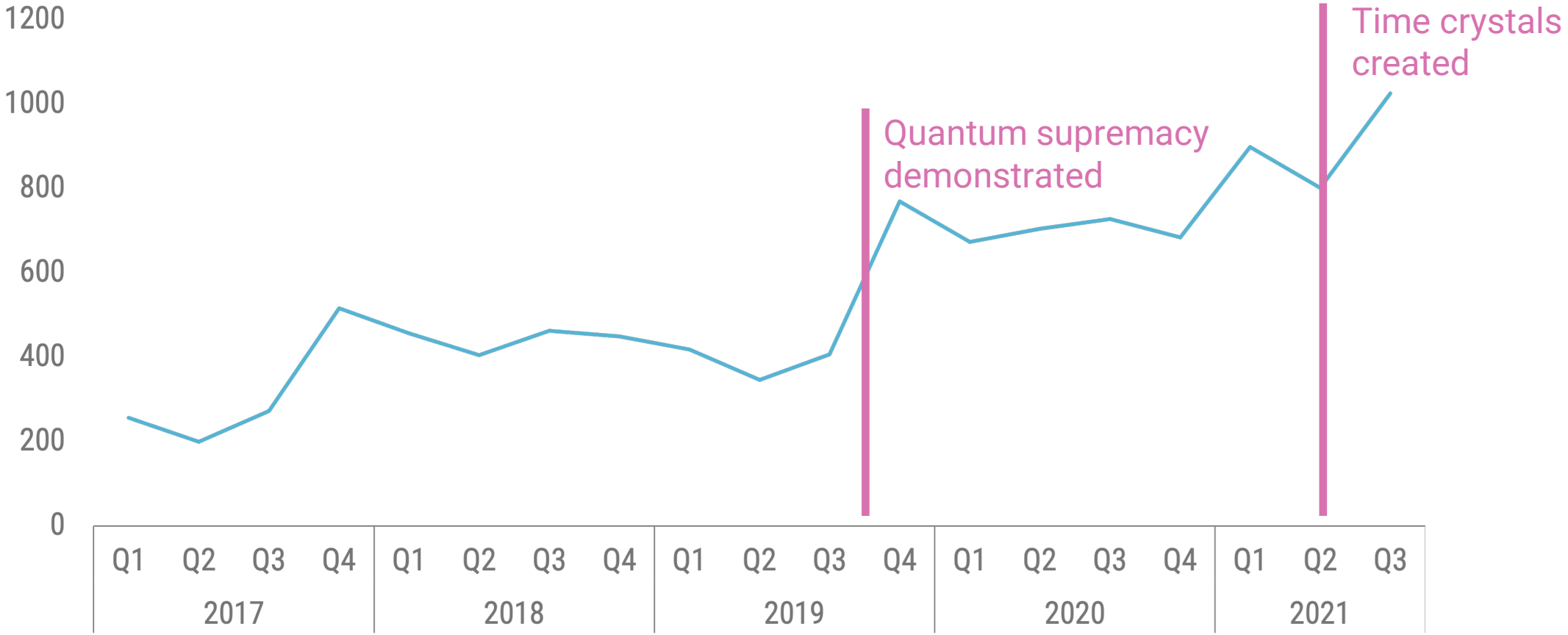
Google partners liberally on quantum initiatives

Google has partnered with several quantum computing startups — including QSimulate, IonQ, AQT, and Pasqal — on quantum computing projects. This helps Google tap into additional industry expertise while more tightly weaving its quantum computing platforms into the broader ecosystem.

The tech giant is also working with numerous university teams and some corporations, including Nvidia and Boehringer Ingelheim.

Google's quantum advances keep it in the news

Mentions of Google and quantum in the media, Q1'17 – Q3'21



CBINSIGHTS Source: CB Insights

AI

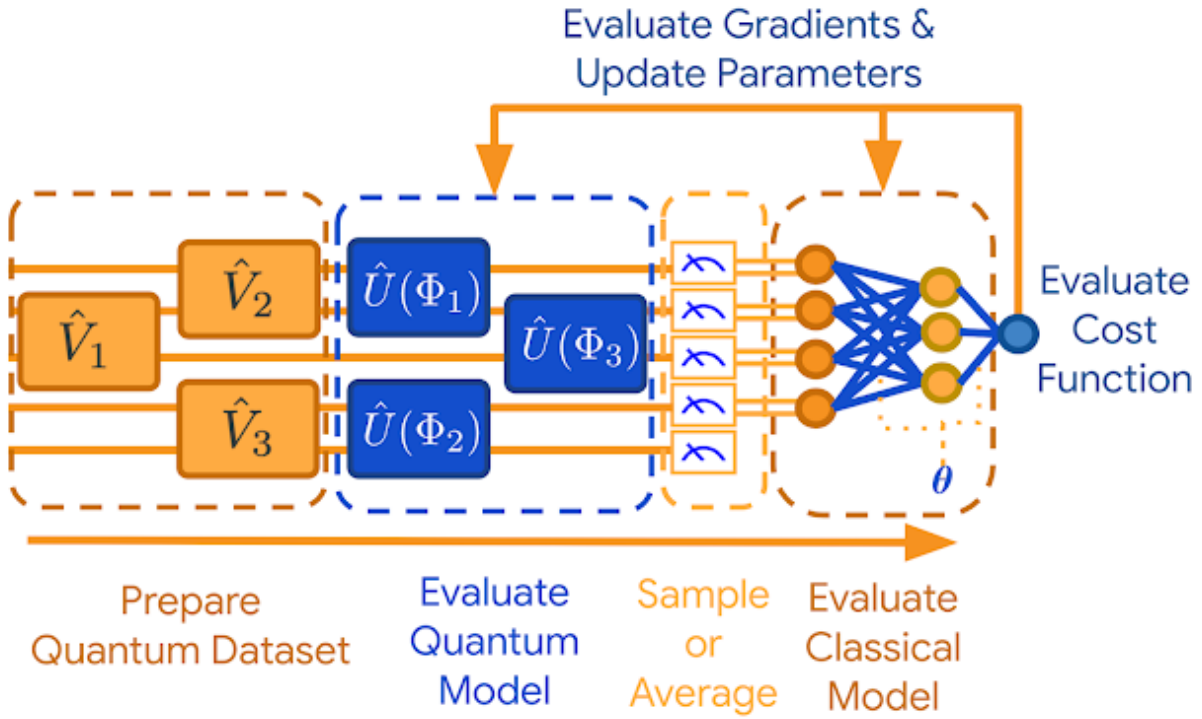
Theme 3: Google could benefit from a quantum AI ripple effect through its businesses

Google thinks that quantum AI is a killer early app

Google's main quantum efforts are branded under Google Quantum AI and the company sees artificial intelligence as a key application of quantum computers — even in the near-term with only moderately powerful machines.

Google has also developed an open-source platform for building quantum machine learning models, TensorFlow Quantum.

Google is building quantum AI applications



 Source: Google

AI is key to Alphabet's long-term business goals

Alphabet is investing heavily in all sorts of AI tools to integrate into its businesses.

Though quantum machine learning is only one aspect of this broader strategy, the company is indicating through its big bets in the space that it is bullish on the tech. If it succeeds, then Alphabet could use quantum computing to eventually boost AI initiatives across its entire business.

"As we are thinking about AI, it all starts with foundational R&D we do. I think we are one of the largest R&D investors in AI in the world. And so thinking ahead and doing that and we are doing it across all the foundational areas and we are taking many diverse approaches."

— **Sundar Pichai**, Alphabet CEO, Q1'21 earnings call

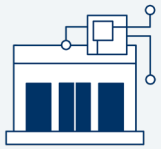
Alphabet's businesses are set to go quantum

Many of Alphabet's businesses make use of AI in some capacity. These areas could be given a significant boost by advances in quantum AI, including business lines like:

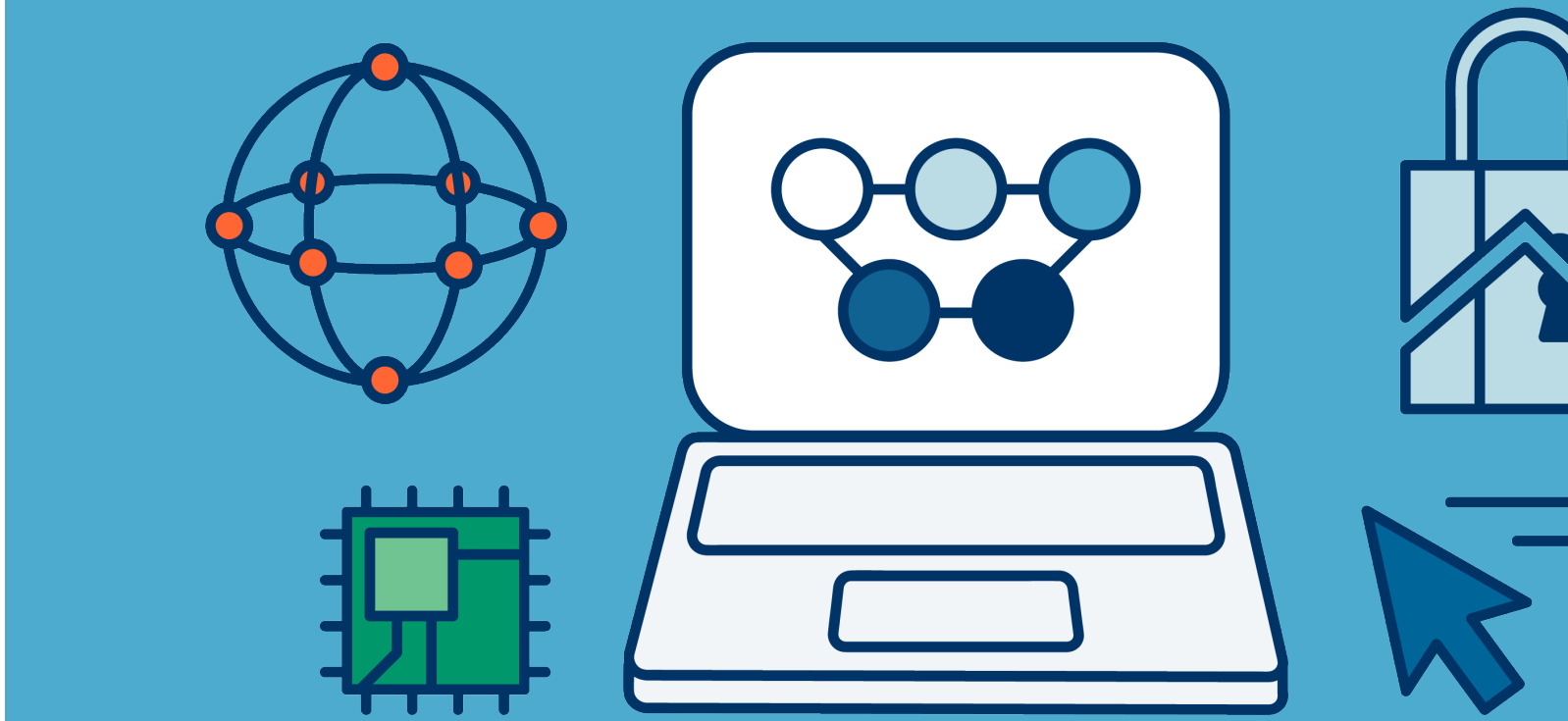
- **Search and ads** — Quantum computing will allow for better ways to parse through big datasets quickly. Advances in natural language processing (NLP) that stem from quantum machine learning could help deliver more relevant and targeted search results and ads.
- **Waymo** — Quantum machine learning could help AI make faster decisions based on less data. Applying this to self-driving car tech could help autonomous vehicles better adapt to dynamic situations on the fly.
- **Google Assistant** — Just as quantum NLP could help Google better understand websites, it could also help its voice assistant better interpret requests. The company may be hoping to gain a quantum edge over rival voice assistants.
- **Google Cloud** — As well as offering cloud-based quantum computing services to enterprises, Google could use quantum algorithms to better manage tasks like cloud data storage.
- **DeepMind** — DeepMind has built a reputation on pushing AI capabilities to the edge, like with its protein folding prediction tool for drug discovery. Quantum machine learning would amplify many of DeepMind's tools and may eventually help defend against competitors looking to catch up with it.

KEY TAKEAWAYS & IMPLICATIONS

Google's plans point to key trends for 2022

Theme	 Google is building cutting-edge quantum technology	 Google has made scientific breakthroughs	 Google could benefit from a quantum AI ripple effect
Takeaways	The company is investing heavily in building advanced quantum computers and is exploring other quantum technologies and software applications.	Google has been involved in multiple quantum breakthroughs over the last few years and is pursuing more initiatives through partnerships.	Google's significant backing of quantum AI could lead to benefits across many key business lines.
Implications	Google wants to own the entire quantum tech stack. By building its own computers, software, and end-user products, it is positioning itself to reap the benefits at every stage of the quantum value chain.	Scientific advances keep Google in news headlines and cement its positioning as a quantum leader. Partnerships with quantum research teams help the company push the capabilities of its systems while promoting its platform across the broader quantum ecosystem.	Quantum computing can open new revenue streams for Google while also offering an opportunity to build a quantum moat around its current businesses. Over the coming years, expect quantum tech to be integrated, sometimes quietly, across Google's product lines.

Microsoft

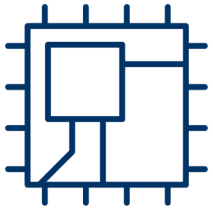


CBINSIGHTS

WHERE MICROSOFT IS FOCUSING

THEME 1

Microsoft is positioning itself as an early quantum cloud leader



THEME 2

Microsoft wants its own quantum hardware — in-house efforts have faced setbacks, but it has also invested in a major quantum computing startup

THEME 3

Microsoft has made post-quantum cryptography moves to get ahead of one of quantum computing's biggest security implications

CLOUD

Theme 1: Microsoft is positioning itself as an early quantum cloud leader

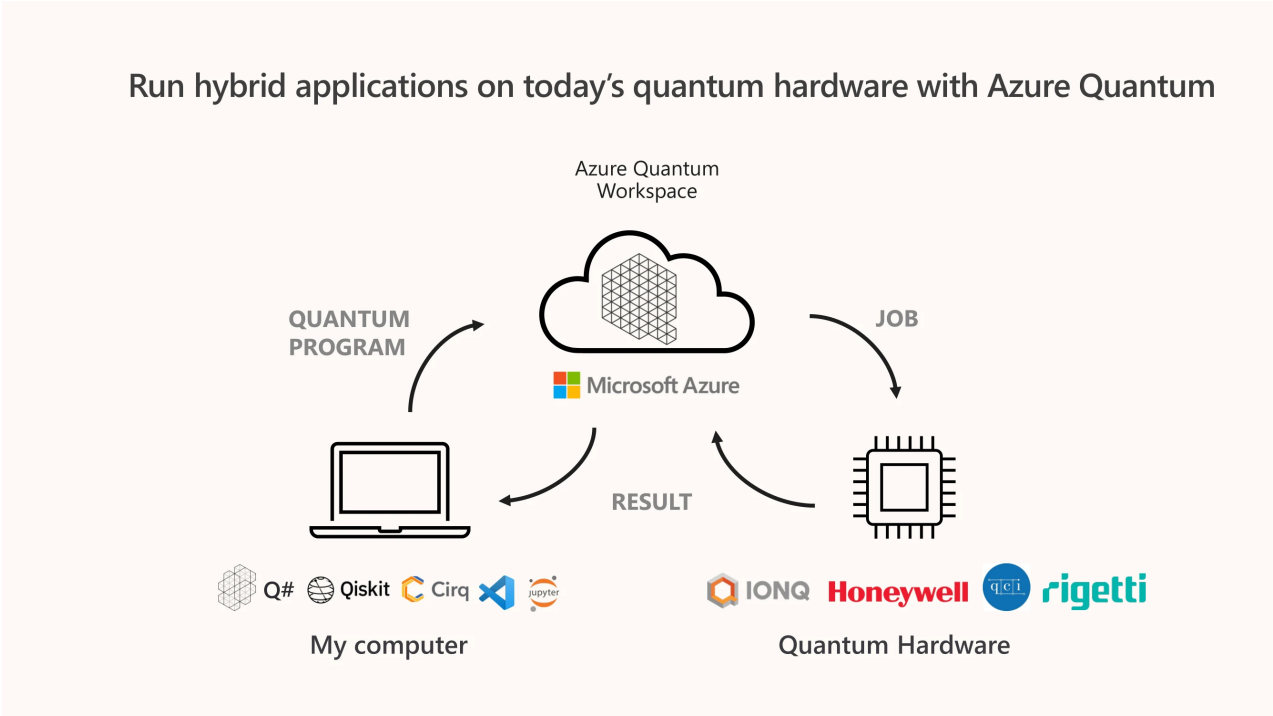
Microsoft has opened Azure Quantum to the public

Microsoft recently began offering its Azure Quantum service in public preview.

The platform offers cloud access to quantum computers and software development tools.

Microsoft is looking to establish itself as an early leader in quantum cloud services — the model widely expected to become the way most enterprises access quantum computers.

Microsoft's quantum cloud services



 Source: Microsoft

Microsoft has a growing roster of quantum computer providers

Microsoft doesn't currently offer quantum hardware itself. Instead, it has partnered with several quantum hardware makers — including IonQ, Quantum Circuits, Rigetti, and Honeywell (which recently spun out its quantum unit to form Quantinuum).

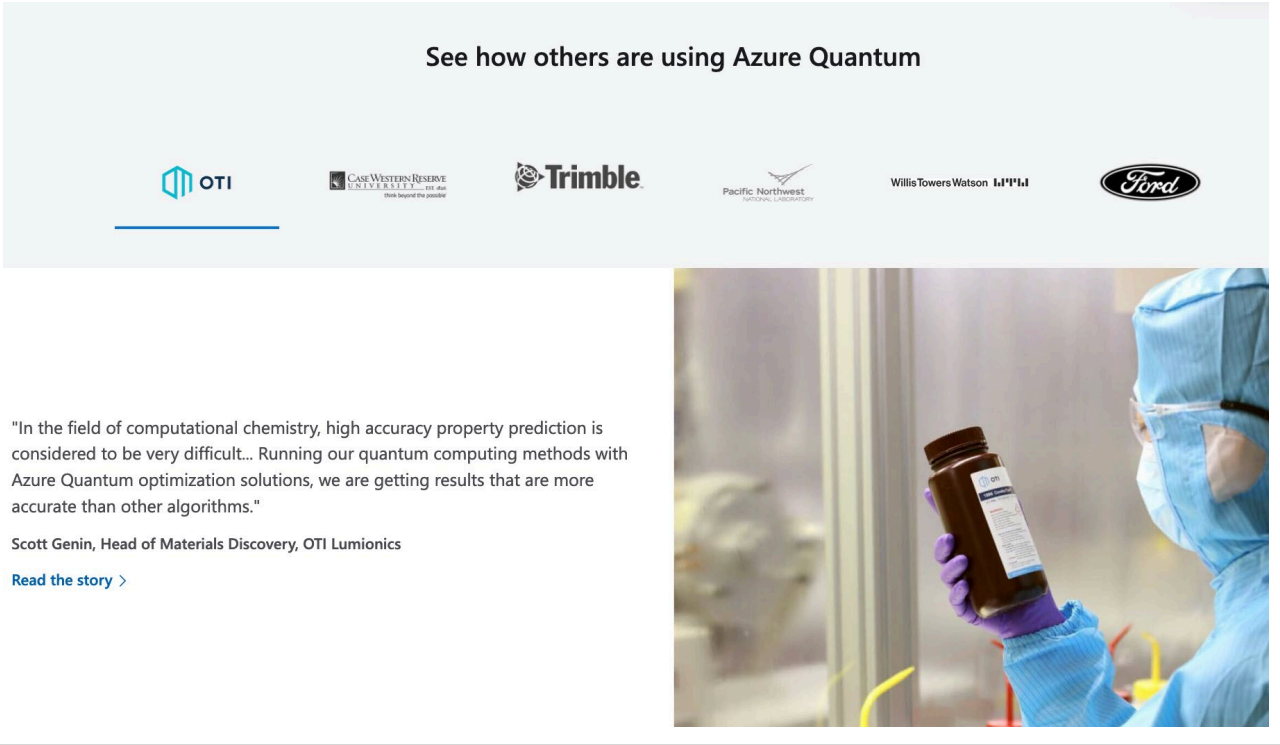
It also offers access to Toshiba's quantum-inspired "simulated bifurcation machine" for optimization problems and 1QBit's 1Qloud software.

Microsoft is doubling down on its enterprise focus

Reflecting its current key client base, Microsoft is building its Azure Quantum platform around enterprise use cases.

For instance, Microsoft has partnered with KPMG to deploy the tech giant's "quantum-inspired optimization" services — which run on classical machines but use quantum emulation to outperform conventional approaches — to the accounting firm's clients.

Microsoft is targeting enterprises with quantum



 Source: Microsoft

HARDWARE

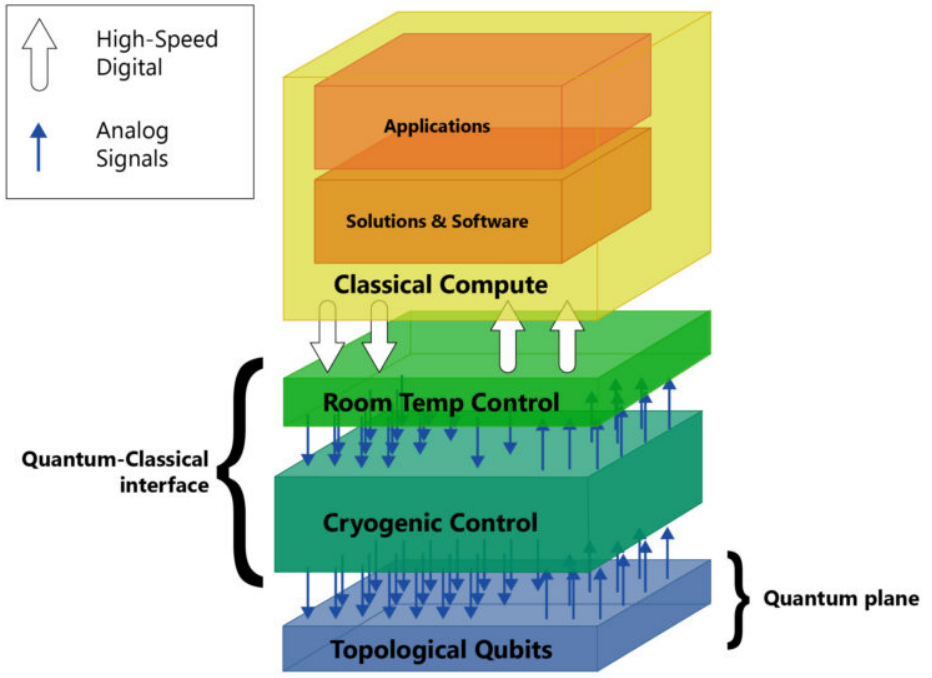
Theme 2: Microsoft wants its own quantum hardware

Microsoft is playing the long game with a differentiated approach to qubits

Microsoft hasn't announced a full quantum computer yet, but it is investing in various levels of the quantum computing stack — including systems for qubit control.

The tech giant is betting on "topological qubits" using Majorana particles, which could help resolve the error correction issues that plague today's quantum computers. If successful, this approach could allow Microsoft to scale its machines much more quickly.

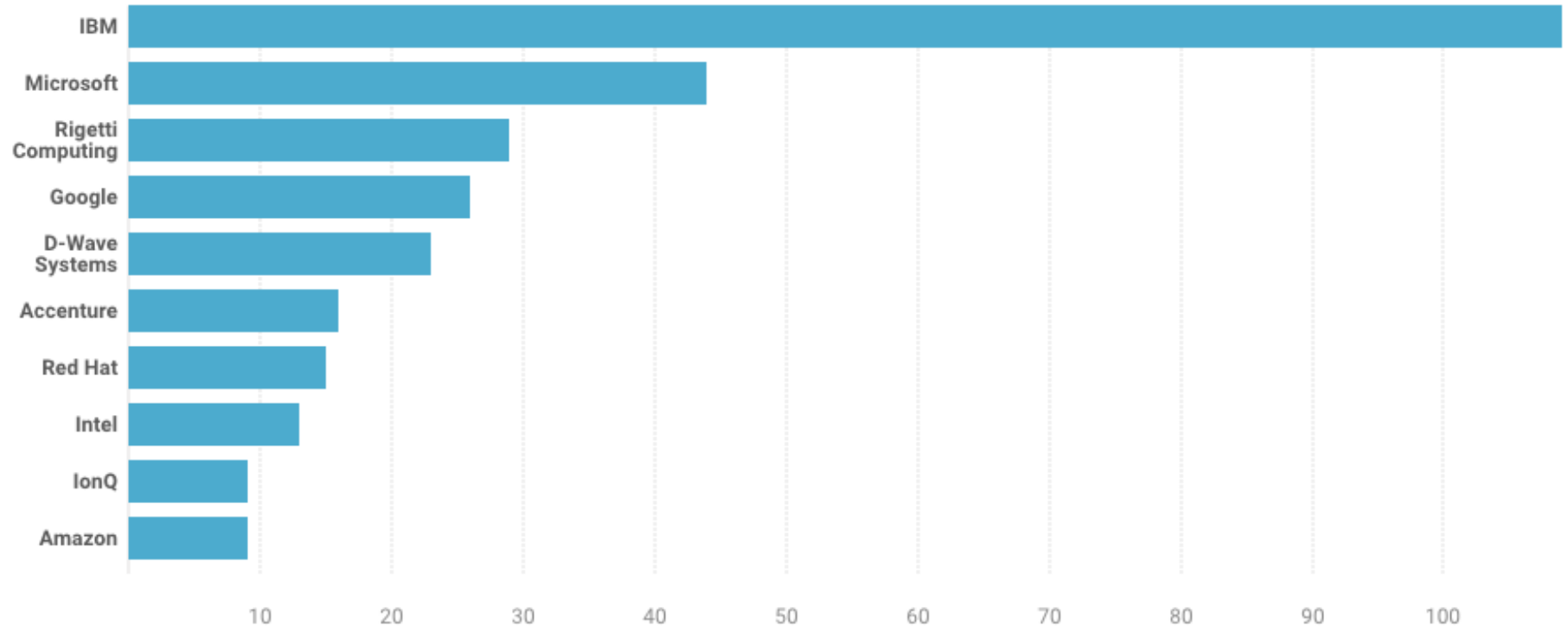
Microsoft's envisioned quantum stack



Source: Microsoft

Microsoft is the #2 quantum computing patent holder

Quantum computing patents filed with USPTO, 2000 – 2021



CBINSIGHTS Source: CB Insights

Its topological qubit hunt has seen recent setbacks, but could still pan out

Evidence of elusive Majorana particle dies — but computing hope lives on

March 10, 2021 | nature

Microsoft's Big Win in Quantum Computing Was an 'Error' After All

February 12, 2021 | WIRED

One-dimensional quantum nanowires fertile ground for Majorana zero modes

January 19, 2021 | EurekAlert! AAAS

Major(ana) Backpedaling: Microsoft-Backed Quantum Computer Research Retracted

March 17, 2021 | Quanta magazine

Microsoft might have a quantum backup plan

Microsoft's venture arm, M12, has invested in multiple rounds to PsiQuantum — the most well-funded quantum computing startup in the world, having raised $729M.

The company is working on a photonic-based approach to quantum computing that's compatible with today's semiconductor tech. (It has already partnered with major manufacturer GlobalFoundries.)

The company claims that it will have a 1M-qubit machine by the middle of the decade.

If PsiQuantum's approach bears fruit, it would be a natural acquisition target for Microsoft.

PSIQUANTUM

Latest round: Series D **Amount:** $450M

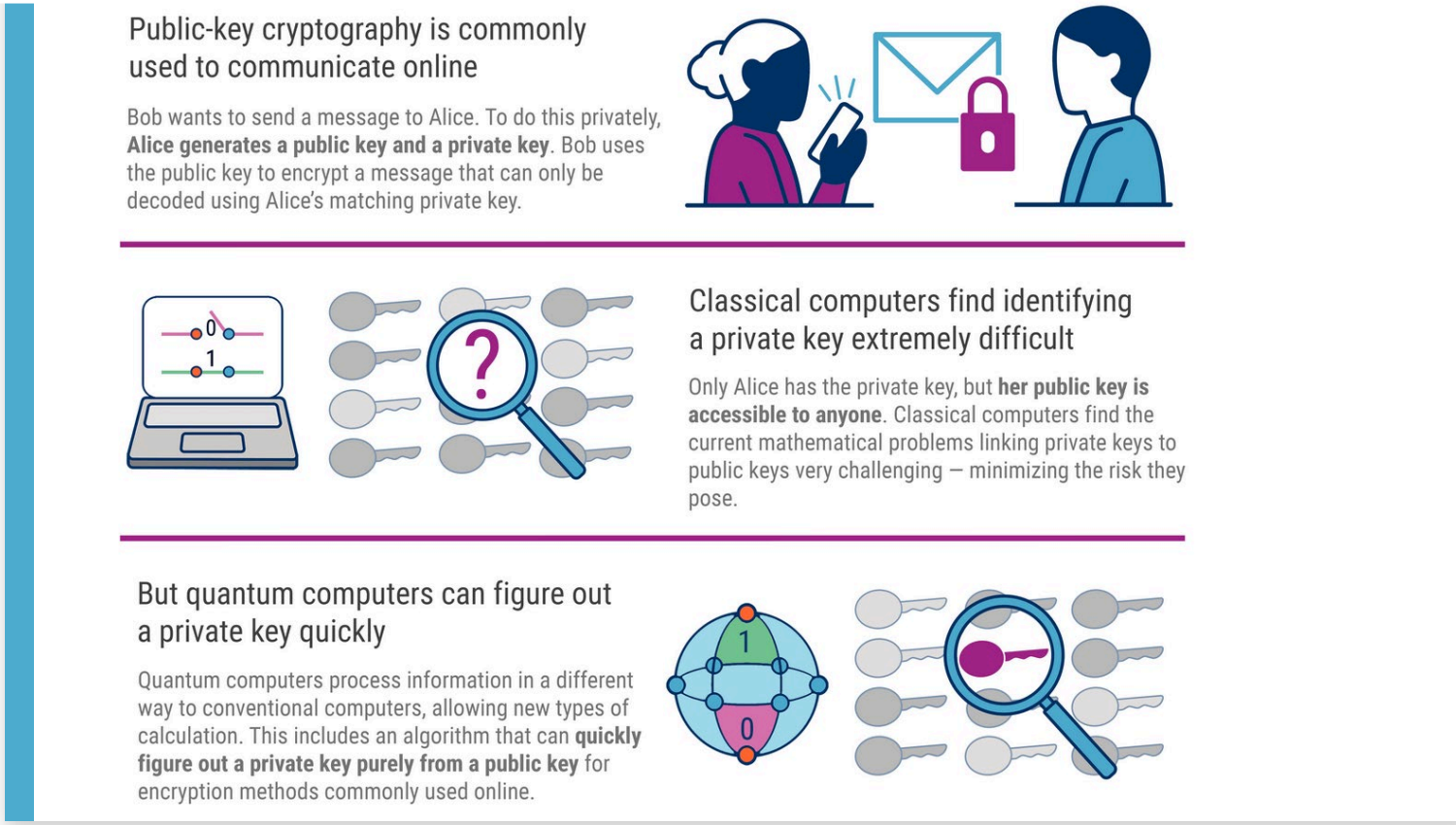
About: PsiQuantum is working on using silicon photonics to build a large-scale quantum computer. The company has raised from investors including M12, BlackRock, Baillie Gifford, Temasek, and Founders Fund, among others.

Theme 3: Microsoft is a post-quantum cryptography pioneer

Quantum computers threaten the internet

Quantum computers process information in a fundamentally different way than their classical counterparts. Eventually, they will be able to quickly crack many of today's public-key encryption methods — a form of encryption that underpins the security of emails, payments, digital certificates for proving the authenticity of websites, and more.

Enterprises that don't adapt to this threat will be at a big cybersecurity disadvantage.



Microsoft wants to prepare its product ecosystem for the quantum timebomb

Post-quantum cryptography (PQC) is a collective term for new public-key encryption approaches that are resistant to quantum computers.

Microsoft is investing in developing multiple PQC protocols for a range of applications.

This indicates that Microsoft expects a powerful quantum computer to emerge in the not-too-distant future and that it's eager to get ahead of any potential security threat to its online services.

Microsoft's post-quantum cryptography projects

FrodoKEM

FrodoKEM is based upon the Learning with Errors problem, which is, in turn, based upon lattices.

SIKE

SIKE (Supersingular Isogeny Key Encapsulation) uses arithmetic operations of elliptic curves over finite fields to build a key exchange.

Picnic

Picnic is a public-key digital signature algorithm, based on a zero-knowledge proof system and symmetric key primitives.

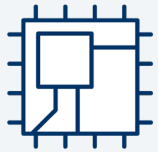
qTESLA

qTESLA is a post-quantum signature scheme based upon the Ring Learning With Errors (R-LWE) problem.

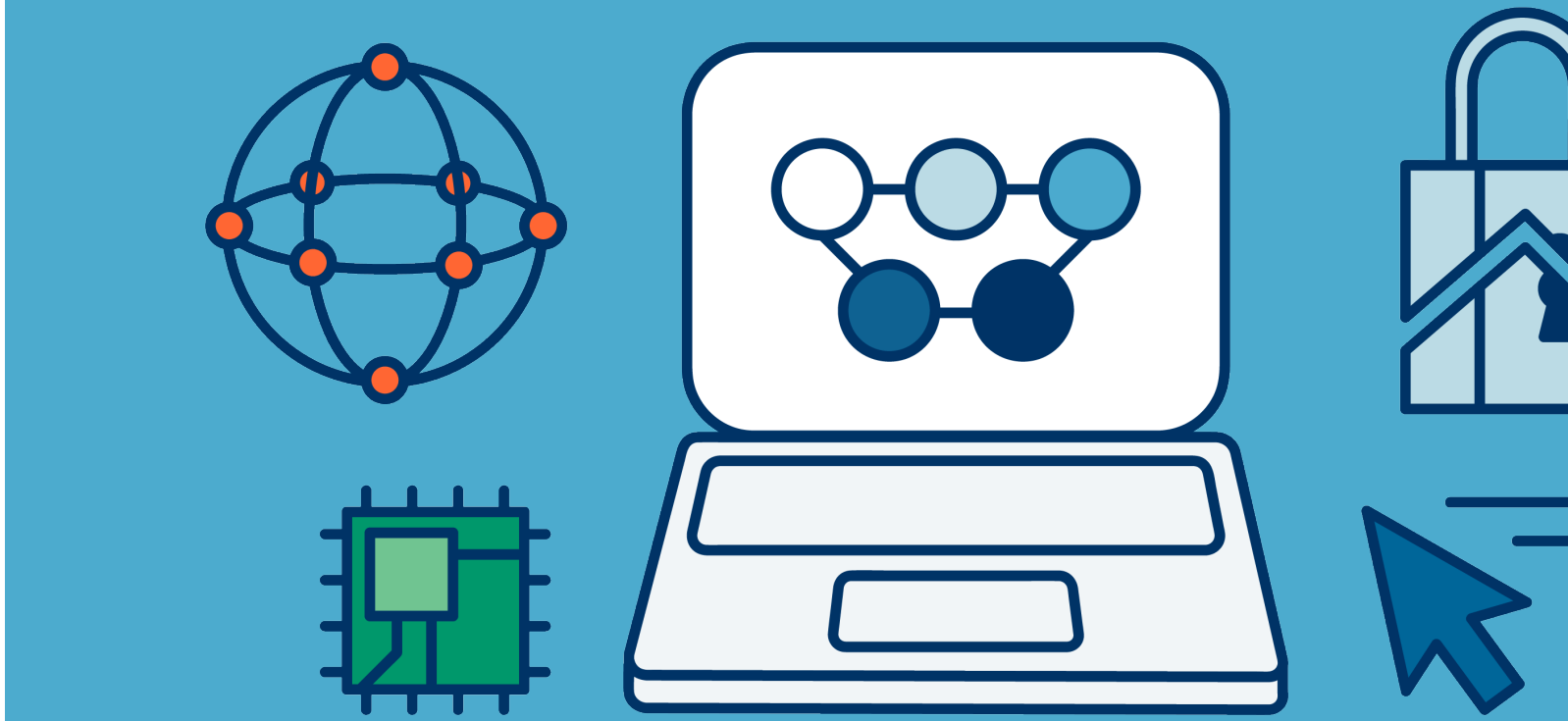
Source: Microsoft. To find out more about post-quantum cryptography and what businesses need to consider, check out our explainer.

KEY TAKEAWAYS & IMPLICATIONS

Microsoft's plans point to key trends for 2022

Theme	 Microsoft is positioning itself as an early quantum cloud leader	 Microsoft wants its own quantum hardware	 Microsoft is a post-quantum cryptography pioneer
Takeaways	Microsoft is building out a robust quantum cloud offering that it has already made available to the public.	The tech giant is aiming to build its own quantum hardware, but its efforts have faced recent setbacks.	Microsoft is developing multiple approaches to post-quantum cryptography.
Implications	Accessing quantum computers via cloud services is expected to be the main way that enterprises tap into quantum computing. Microsoft is doubling down on its enterprise focus and wants to build up partnerships in this area to establish itself early.	Not controlling its own quantum computing hardware could make Microsoft vulnerable to big tech rivals. The company is betting on an unproven approach to quantum computing, but one that could allow it to scale quickly. If this fails, then expect Microsoft to makes moves to acquire a quantum computer maker.	Quantum computers threaten much of the encryption that underpins online services. Microsoft is looking to get ahead of this threat — especially for lucrative, enterprise-focused business lines like Azure. Expect the company to highlight its security credentials as post-quantum cryptography goes mainstream.

Amazon

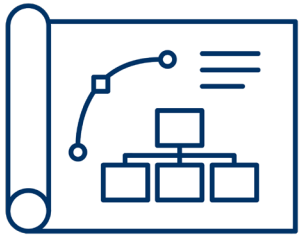


CBINSIGHTS

WHERE AMAZON IS FOCUSING

THEME 1

Amazon sees quantum computers as key to the future of AWS



THEME 2

Amazon is developing its own quantum hardware

THEME 3

Amazon's current businesses, including e-commerce, could be given a big boost by quantum computers

CLOUD

Theme 1: Amazon sees quantum computers as key to the future of AWS

Amazon has partnered with startups to launch a quantum service on AWS

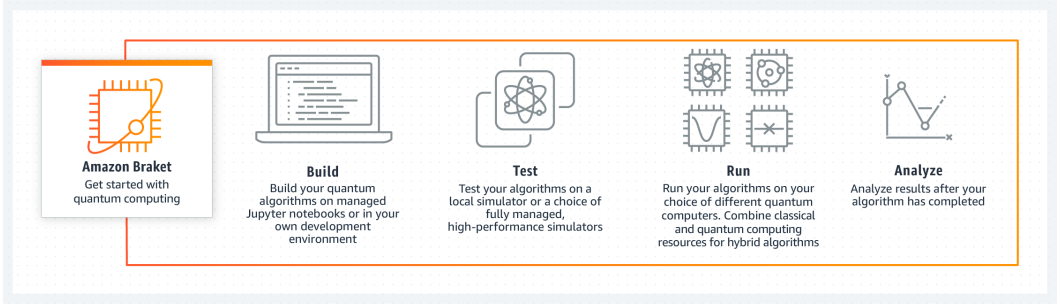
Amazon has partnered with quantum computer makers D-Wave, IonQ, Rigetti, OQC (Oxford Quantum Circuits), and QuEra for its quantum cloud service, Amazon Braket.

Amazon wants to make quantum computing feel accessible

Amazon is positioning its Braket cloud services as an accessible way for organizations to begin experimenting with quantum computers.

It offers a free tier and provides access to quantum experts for collaborations. It includes startups and research institutions among its highlighted customers.

Amazon wants cloud customers to use Braket to explore quantum computing's potential



Customers

FCAT FIDELITY CENTER for APPLIED TECHNOLOGY — Fidelity created quantum proofs-of-concept for financial asset management »

Qu & Co — Qu & Co built their QUBEC computational software to run chemistry simulations »

MS&AD 三井住友海上 — Aioi Insurance Services tests quantum neural network to assess risk »

INFN — The Italian National Institute for Nuclear Physics accelerates quantum research »

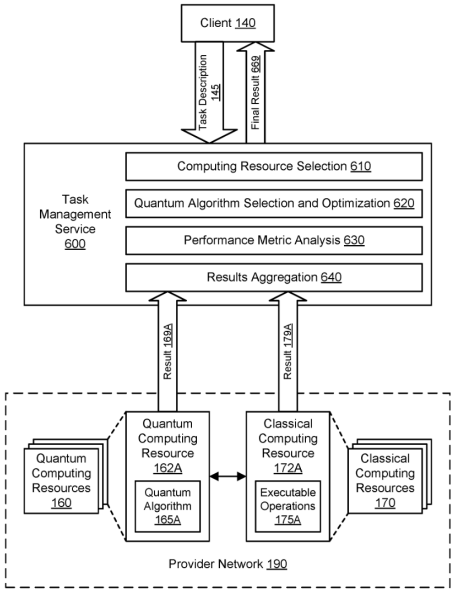
 Source: Amazon

Amazon has patented quantum cloud technology

Amazon has been granted several patents related to quantum cloud services. These include descriptions of schemes for:

- Cloud-based access to multiple quantum computers
- Cloud-based quantum simulation
- Post-quantum cryptography
- A development environment for programming quantum computers

Amazon has patented ways to bring quantum to its cloud services



HARDWARE

Theme 2: Amazon is developing its own quantum hardware

Amazon launches into building its own quantum computer

Amazon joins race for quantum computer with new Caltech center

October 26, 2021 | The Washington Post

Caltech and Amazon Partner to Create New Hub of Quantum Computing

October 26, 2021 | Caltech

Amazon Is Laying the Groundwork for Its Own Quantum Computer

December 1, 2020 | Bloomberg

Amazon's New Quantum Computer Design Relies On Tiny Schrödinger's Cats

April 20, 2021 | IEEE Spectrum

Amazon is helping to develop quantum applications

Amazon partnered with BMW to run a competition focused on developing quantum-based solutions for vehicle manufacturing problems like sensor position optimization.

In addition to promoting Amazon's quantum cloud services, the competition gives Amazon insight into quantum computing approaches from leading teams in the industry. This could inform its approach to building quantum computing hardware.

The BMW Challenge 2021 winners for quantum computing use cases

 Source: BMW

Theme 3: Amazon’s current business lines could be given a big boost by quantum computers

Amazon's businesses have a quantum opportunity

Many of Amazon's revenue streams could eventually benefit from advances in quantum computing. This includes business lines like:

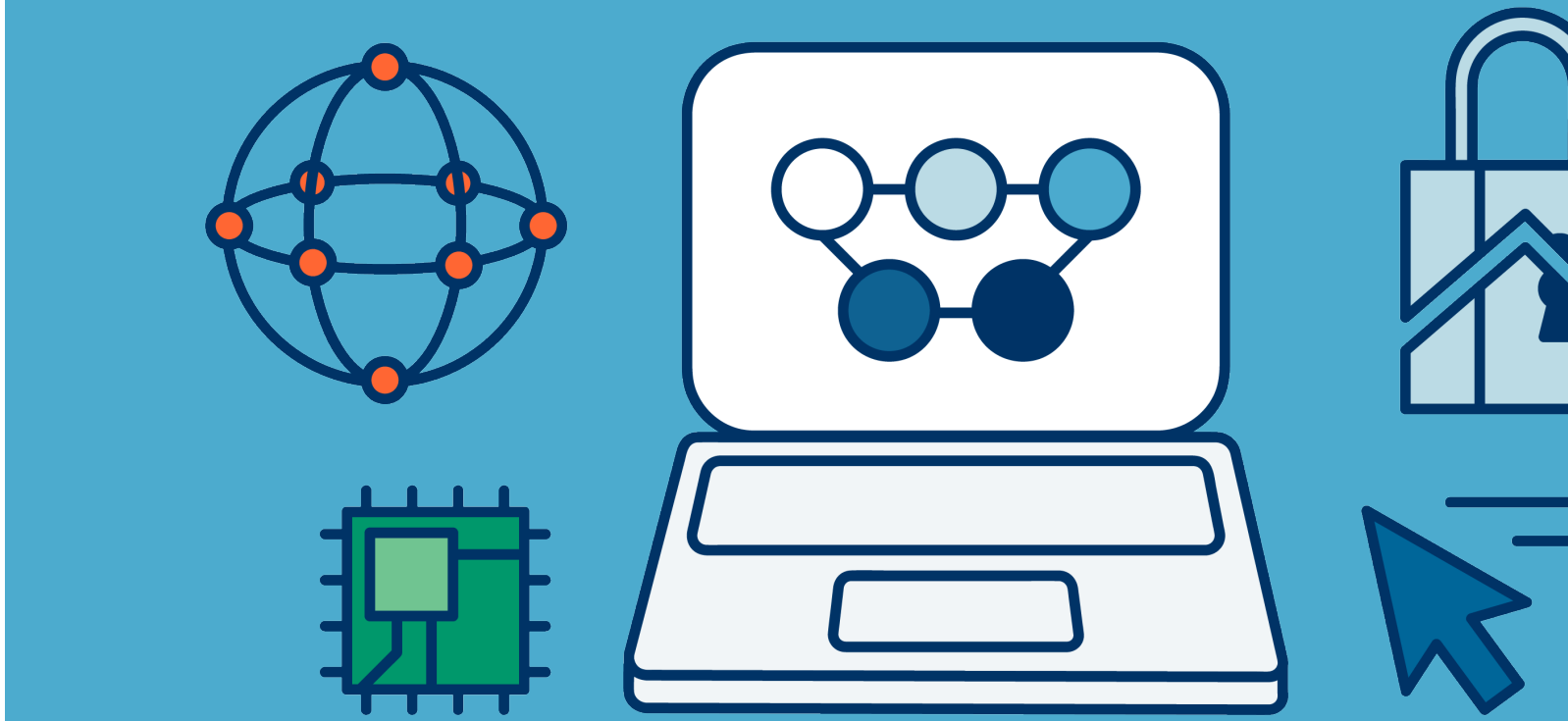
- **E-commerce and delivery** — Quantum computers' knack for solving optimization problems could help Amazon push its mastery of logistics to the next level. Meanwhile, Amazon Braket has already been employed to explore using quantum computing to build recommendation engines that need less data to return good results.
- **Alexa** — Quantum machine learning is expected to improve the performance of natural language processing systems used by voice assistants like Alexa. By building its own quantum computer, Amazon may be hoping to stay competitive with rival AI powerhouses with quantum ambitions, like Google.
- **Amazon Healthcare** — Amazon has made moves to optimize the pharma supply chain and may even begin developing its own generic drugs. Quantum computers' capacity for more accurate simulations could eventually speed up the design and testing of generic drugs, shortening the time to get them to market. Separately, quantum computing could be used to help solve drug supply chain optimization problems.
- **AWS** — As well as offering quantum services on AWS, Amazon may build off recent research showing that quantum computers can help with the management of cloud data storage to improve efficiency and reduce operating costs for AWS. This could further strengthen AWS' cost advantage moat.

KEY TAKEAWAYS & IMPLICATIONS

Amazon's plans point to key trends for 2022

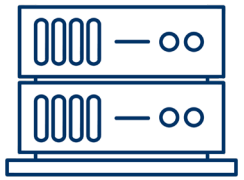
Theme	 Amazon sees quantum computers as key to the future of AWS	 Amazon is developing its own quantum hardware	 Amazon's current business lines could be given a boost by quantum computers
Takeaways	Amazon has already integrated quantum computing into AWS and is offering the service to enterprises.	Amazon is investing in building its own quantum computer and is helping to develop business use cases.	Amazon's core business lines stand to benefit from advances in quantum computing.
Implications	Quantum capabilities will become an increasingly central part of cloud services like AWS. Amazon is positioning itself to get ahead of the curve and keep growing the service as quantum computers advance.	The tech giant doesn't want to miss out on quantum computing. It may see outsourcing the development of quantum hardware as risky, given the competitive gains that rivals could enjoy if they secure preferential access to powerful machines.	If Amazon can lead in quantum computing, then many advantages it currently enjoys, like logistics prowess, could be strengthened. But competitors across its business lines could also use quantum computing to challenge the e-commerce behemoth if it falls behind in quantum innovation.

IBM



CBINSIGHTS

WHERE IBM IS FOCUSING



THEME 1

IBM is going after the full quantum computing stack

THEME 2

IBM positions itself as the essential quantum computing partner for enterprises

HARDWARE

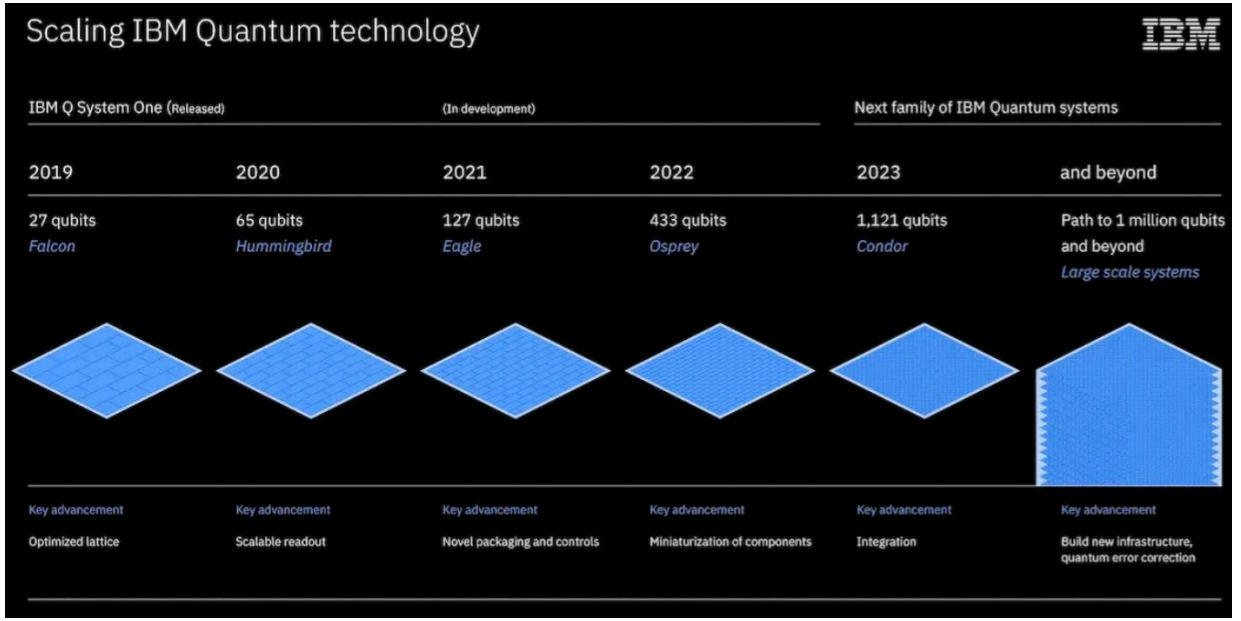
Theme 1: IBM is going after the full quantum computing stack

IBM just debuted a leading 127-qubit machine and has an ambitious roadmap

IBM launched its 127-qubit Eagle processor in late 2021 — one of the most powerful quantum computers in the world. It is aiming to scale up rapidly to 1,121 qubits by 2023.

IBM eventually plans to create a 1M-qubit quantum computer architecture that it can house in sizable "super fridges" — reminiscent of the big mainframes that helped bring IBM to prominence in the early days of classical computing.

IBM wants to scale quantum computing quickly



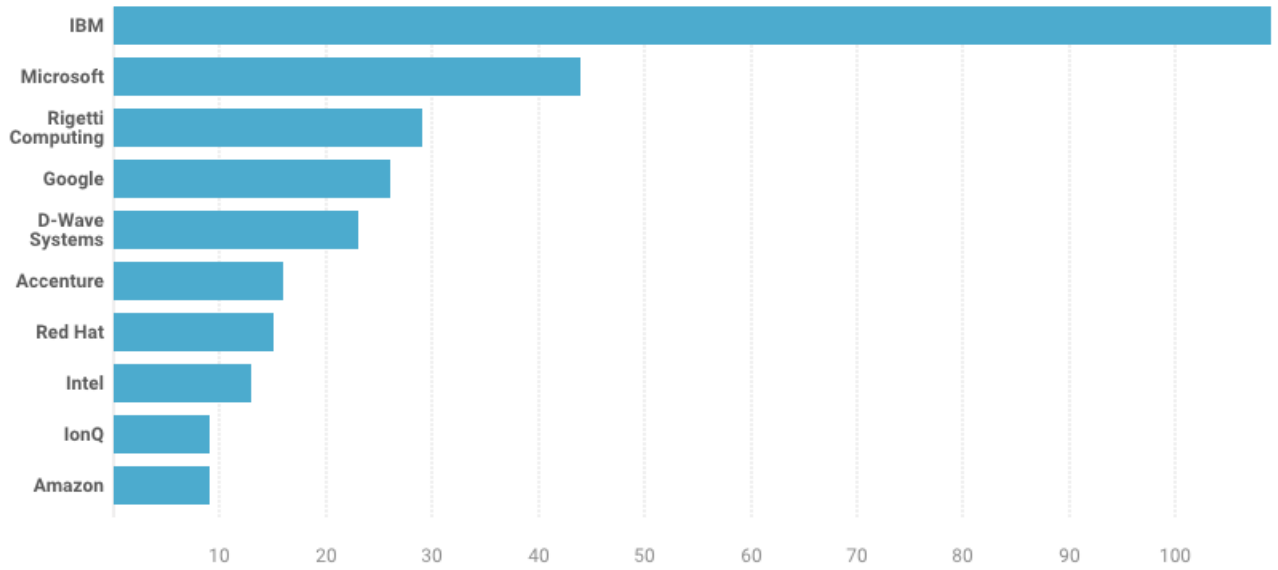
Source: IBM

IBM has more quantum computing patents than its big tech rivals combined

IBM has 100+ quantum computing patents filed with the US patent office. This is more than any other company and surpasses the combined total of Microsoft, Google, Intel, and Amazon.

Red Hat, a software-focused firm that was acquired by IBM for $34B in 2019, is also a quantum computing patent leader.

IBM pulls ahead for quantum computing patents



Source: CB Insights

IBM invested in a quantum software startup

IBM invested in Cambridge Quantum prior to the startup's merger with Honeywell's quantum unit.

Cambridge Quantum had previously partnered with IBM to use the company's quantum computers to help develop quantum algorithms.

CAMBRIDGE QUANTUM

Cambridge Quantum

Latest round: Merger **Amount:** N/A

About: Cambridge Quantum focuses on developing quantum algorithms for applications like machine learning and quantum chemistry. The company merged with Honeywell's quantum business unit to form Quantinuum in 2021.

Theme 2: IBM positions itself as the essential quantum computing partner for enterprises

IBM offers a quantum cloud service geared toward enterprises

With quantum computing, IBM is doubling down on its historical enterprise focus. It wants to become the essential partner for large companies looking to capitalize on the emerging tech and hopes to pocket a slice of its clients' quantum gains.

"Quantum has the potential to unlock hundreds of billions of dollars of value for our clients by the end of the decade." — **Arvind Krishna**, IBM CEO, Q1'21 earnings call

IBM Quantum Network has attracted scores of big corporations

We're building the future of quantum *together*

IBM's full quantum stack allows our partners to fully explore quantum solutions at unmatched fidelity and scale.

Learn the benefits of joining the IBM Quantum Network – our community of 170+ Fortune 500 companies, academic institutions, national labs, and startups. These organizations gain access to our stack, empowering them to tackle the hardest problems across fields like finance, materials, logistics, and chemistry in new and better ways.

DAIMLER · ExxonMobil · accenture · Goldman Sachs · JPMorgan Chase & Co. · JSR · Mitsubishi Chemical · SONY · MIZUHO · SAMSUNG · BOEING · Massachusetts Institute of Technology

IBM announced a flurry of quantum collaborations with major companies in 2021

E.ON allies with IBM Quantum to Advance Energy Transition Goals

September 2, 2021 | e·on

Lockheed Martin Canada joins the IBM Quantum Hub at Institut Quantique

December 1, 2021 | LOCKHEED MARTIN

NVIDIA Teams With Google Quantum AI, IBM and Other Leaders to Speed Research in Quantum Computing

December 1, 2021 | NVIDIA

ExxonMobil & IBM Explore Quantum Algorithms to Solve Routing Formulations

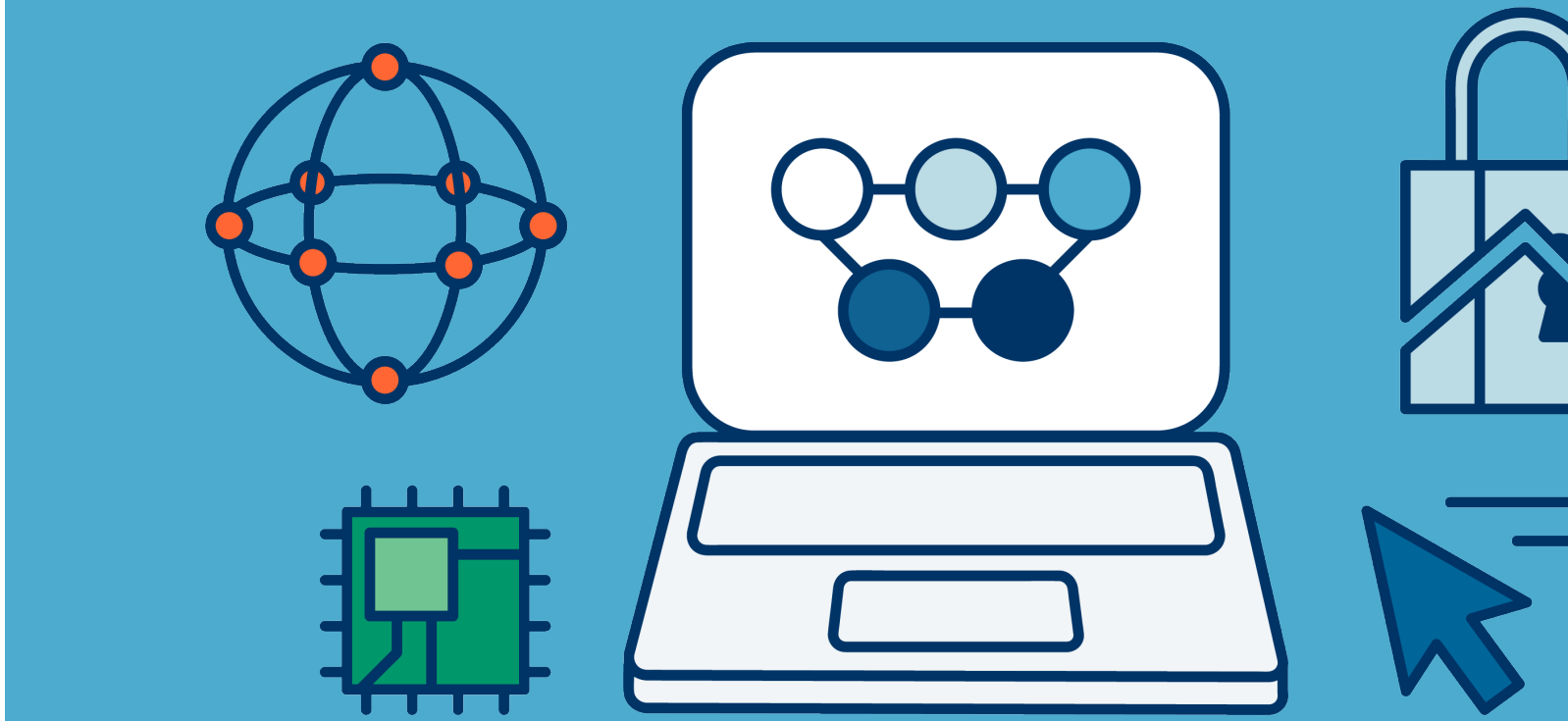
February 9, 2021 | ExxonMobil

KEY TAKEAWAYS & IMPLICATIONS

IBM's plans point to key trends for 2022

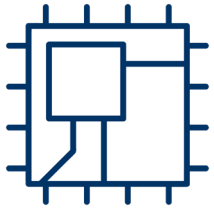
Theme	 IBM is going after the full quantum computing stack	 IBM positions itself as the essential quantum computing partner for enterprises
Takeaways	IBM is investing heavily in developing quantum computing hardware and plans to build massive, mainframe-style quantum machines.	IBM is positioning itself to be a key quantum partner for enterprises looking to apply the tech to their own businesses.
Implications	IBM leads in quantum computing patents and currently has the most powerful machine by qubit number among its big tech rivals. The question will be if IBM's quantum interconnected "super fridges" will allow it to scale the tech in the way it hopes, or if a competing approach will prove to have more long-term potential. In the meantime, expect IBM to chalk up quantum milestone after quantum milestone.	IBM does not appear eager to keep the competitive gains quantum computers may offer for itself, instead opting to partner with other large companies to gain exposure across industries. It's hoping that clients can use its devices to generate hundreds of billions of dollars of value — and it plans to take a cut for enabling it. Expect the company to work hard to bring more enterprises onto its platform and cater to more sectors.

Intel



CBINSIGHTS

WHERE INTEL IS FOCUSING

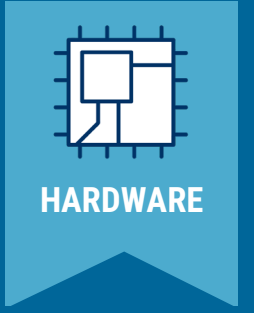


THEME 1

Intel is building quantum processors

THEME 2

Intel is prioritizing post-quantum cryptography



Theme 1: Intel is building quantum processors

Intel is focusing on scaling up quantum computing using its well-established silicon techniques

Intel is pursuing silicon-based quantum computing — which relies on qubits created using semiconductor technology.

The advantage of this approach is that current manufacturing processes could be adapted to help scale up a silicon-based quantum computer.

"We are also investing to lead the next wave of technology breakthroughs such as quantum computing. Our investment in quantum computing covers the full hardware and software stack in pursuit of a practical commercially viable quantum system."

— **Bob Swan**, former Intel CEO, Q4'19 earnings call

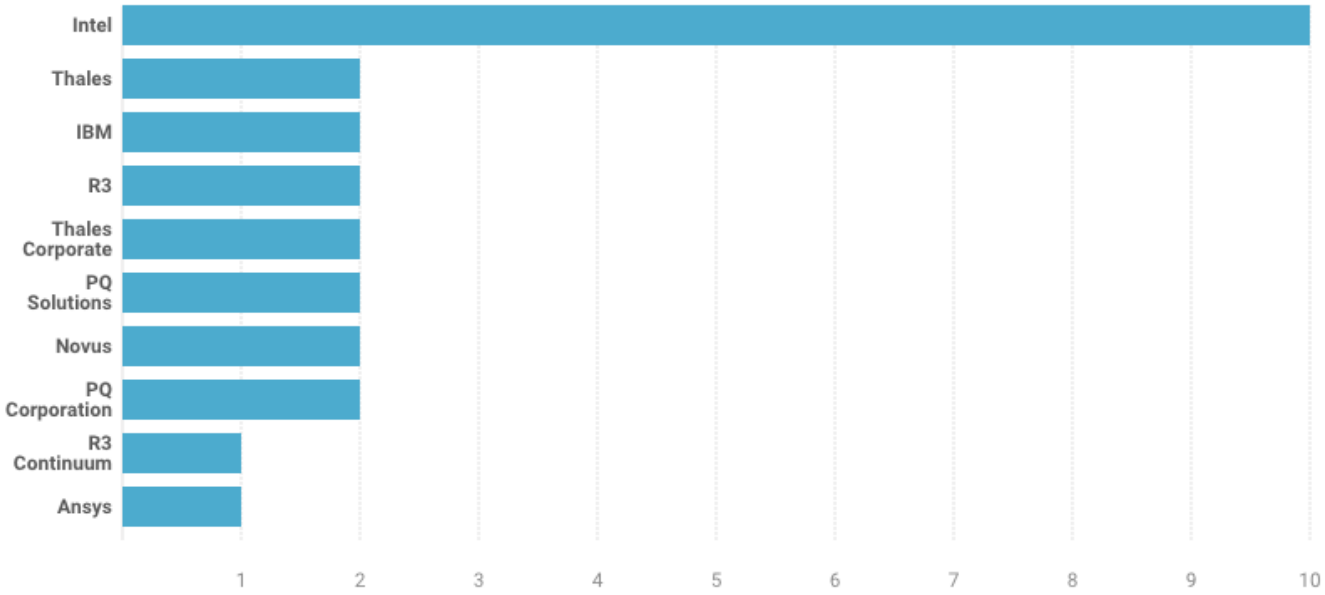
Theme 2: Intel is prioritizing post-quantum cryptography

Intel is taking post-quantum cryptography seriously

Intel has filed by far the most patents mentioning post-quantum cryptography with the US patent office.

Many of these patents relate to making quantum-resistant encryption protocols more computationally efficient. This focus on efficiency could help smooth the transition to post-quantum cryptography across Intel's ecosystem and extend quantum-resistant encryption to low-powered devices used in IoT setups.

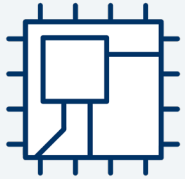
Intel races past rivals for post-quantum cryptography patents



 Source: CB Insights

KEY TAKEAWAYS & IMPLICATIONS

Intel's plans point to key trends for 2022

Theme	 Intel is building quantum processors	 Intel is prioritizing post-quantum cryptography
Takeaways	Intel is developing quantum computing hardware and is focusing on repurposing its semiconductor expertise to scale up quantum computers with conventional manufacturing.	Intel is investing in post-quantum cryptography to protect against the threat that scaled-up quantum computers pose to public-key encryption.
Implications	Intel sees quantum computing as a key technology for the future of processing information. By focusing on silicon quantum computing, it is betting that its well-established understanding of semiconductors can help it leapfrog other quantum computing approaches as the tech matures.	Intel has a vast ecosystem of connected products, including business lines focused on the internet of things. By acting early, it is hoping to avoid the risk that its products could be vulnerable to quantum computing within the lifetime of a device.