McKinsey & Company

Quantum Technology Monitor

June 2022

What does this document provide?

Note: The Quantum Technology Monitor is based on research from numerous data sources (including but not limited to CapitalIQ, Crunchbase, PitchBook, Quantum Computing Report, expert interviews, and McKinsey analysis); minor data deviations may exist due to updates of the respective databases.

- ✓ Continuously evolving overview of the **global quantum technology (QT) player and investment space,** updated biannually
- ✓ Dynamic overview of industries’ **maturity toward QT,** based on the current application of the technology and application of patents
- ✗ **Definitive and exhaustive list** of the start-up and funding activities in the QT realm

Contents

Introduction

Three main areas of quantum technology (QT)—computing, communications, and sensing—enable broad, new capabilities.

Quantum computing (QC) is a new technology for computation, which leverages the laws of quantum mechanics to provide exponential performance improvement for some applications and to potentially enable completely new territories of computing. Some of the early quantum hardware products are special-purpose quantum computers, also called quantum simulators.

Quantum sensing (QS) is the new generation of sensors built from quantum systems. It could provide measurements of various quantities (eg, gravity, time, electromagnetism) that are orders of magnitude more sensitive than classical sensors.

Quantum communications (QComms) is the secure transfer of quantum information across space.[1] It could ensure security of communications, enabled by quantum cryptography, even in the face of unlimited (quantum) computing power. [2]

1. Quantum information is information stored in qubits. Qubits are the unit of information for QC and are an extension of the classical bit (the unit of information for classical computing).
2. Quantum cryptography draws on the exchange of a secret key to encrypt messages based on the quantum mechanical phenomenon of entanglement. Unlike any classical cryptographic protocol, it is in principle not possible to “eavesdrop” on messages exchanged with quantum cryptography. However, early implementations have been shown to have some weaknesses.

Source: Expert interviews

New additions to the Monitor

- University programs directly related to QT
- Current QC talent gap analysis
- Use case value matrix of QC by industry
- Overview of QC technologies with funding split
- Total QT patent counts per technology
- Improved perspective on QT in China

Key developments in 2H2021 in brief

New funding

- $1.24 billion of finalized private investment in start-ups
- $1.9 billion of announced government funding for QT

Ecosystem

- 16 new start-ups in the QC space
- 7 new universities with quantum research groups

Key announcements

- IonQ went public, the first QT start-up in history to do so
- Honeywell Quantum Solutions and Cambridge Quantum officially became Quantinuum
- Rigetti also announced plans to go public as Rigetti Computing after a merger with Supernova, a special purpose acquisition company (SPAC)
- Orgin Quantum delivered a road map to deliver a 1,024-qubit quantum computer by 2025
- AWS opened its Center for Quantum Computing at the California Institute of Technology

Key developments in 2H2021

Funding and ecosystem

- Of the quantum technologies, quantum sensing (QS) and quantum communications (QComms) saw the highest funding increases in 2H2021; however, quantum computing (QC) still has the most funding ($3 billion total since 2001) and players (228).
- Quantum technology (QT) start-up funding and investment activity in 2021 surpassed $1.4 billion—more than twice that of 2020, though the rate of new QT start-up creation has slowed over a longer three-year time frame.
- QT funding moved toward established start-ups—nearly 90 percent of funding is now directed at companies in the Series A, B, C, and D rounds of funding.
- QT activity in China is accelerating due to reported large government investment (estimated at $15.3 billion), more than double what EU governments are investing ($7.2 billion) and more than eight times that of US government investments ($1.9 billion).

Business impact of quantum computing

- New analysis shows the finance and life sciences sectors will likely see the highest impact from QC in the long-term; however near-term impact of QC is still expected to be highest in the chemicals, pharmaceuticals, automotive, and finance industries.

Scientific progress

- China increased its QT patent activity across all technologies and has originated more than half of all QT patents globally.

Quantum computing talent

- The talent gap for QC jobs is wide, with university capacity only about a third of the demand; upskilling programs could address the challenge.
- The European Union has the highest concentration of QT talent.

Public and private funding continues to skyrocket around the world, with North America still investing the most.

The QT market is still concentrated in North America

North America still leads the QT market, with nearly 40% of players and over 60% of all start-up funding[1]

Ten out of the 12 biggest hardware players are based in North America

China has the broadest commercial implementation of QComms. Japan has the most players in the industry adopting QT in some part of their operations

Funding continued its rapid rise

QT founding and investment activity surpassed $1.4 billion in 2021, more than double that of 2020

Major deals for 2021 extend to software and QComms players

China has committed $15 billion over five years for QT; the European Union announced $7.2 billion

Global market participation is increasing

While the United Kingdom began catching up to North America in the first half of 2021, it made no new deals in the second half

China still has the most patents, which is conducive to rapid technology progress

1. Data availability on start-up funding in China is limited. The overviews in this document include all publicly available data on China; however, actual investment is likely higher.

Source: McKinsey analysis

QS and QComms start-ups saw slight investment increases, but QC still has the largest estimated market and number of players.

Number of players[1] | Total raised start-up funding[2] | Estimated market 2040[3]

Quantum computing (QC)

228[1]

$3.0 billion[2]

$9 billion–$93 billion[3]

Quantum computing market estimates still have a high level of uncertainty, caused by:

- Technological challenges in hardware development
- Lack of transparency on business impact due to limited availability of detailed end-to-end quantum solutions

Quantum sensing (QS)

58[1]

$0.4 billion[2]

$1 billion–$7 billion[3]

Quantum communications (QComms)

111[1]

$0.7 billion[2]

$1 billion–$6 billion[3]

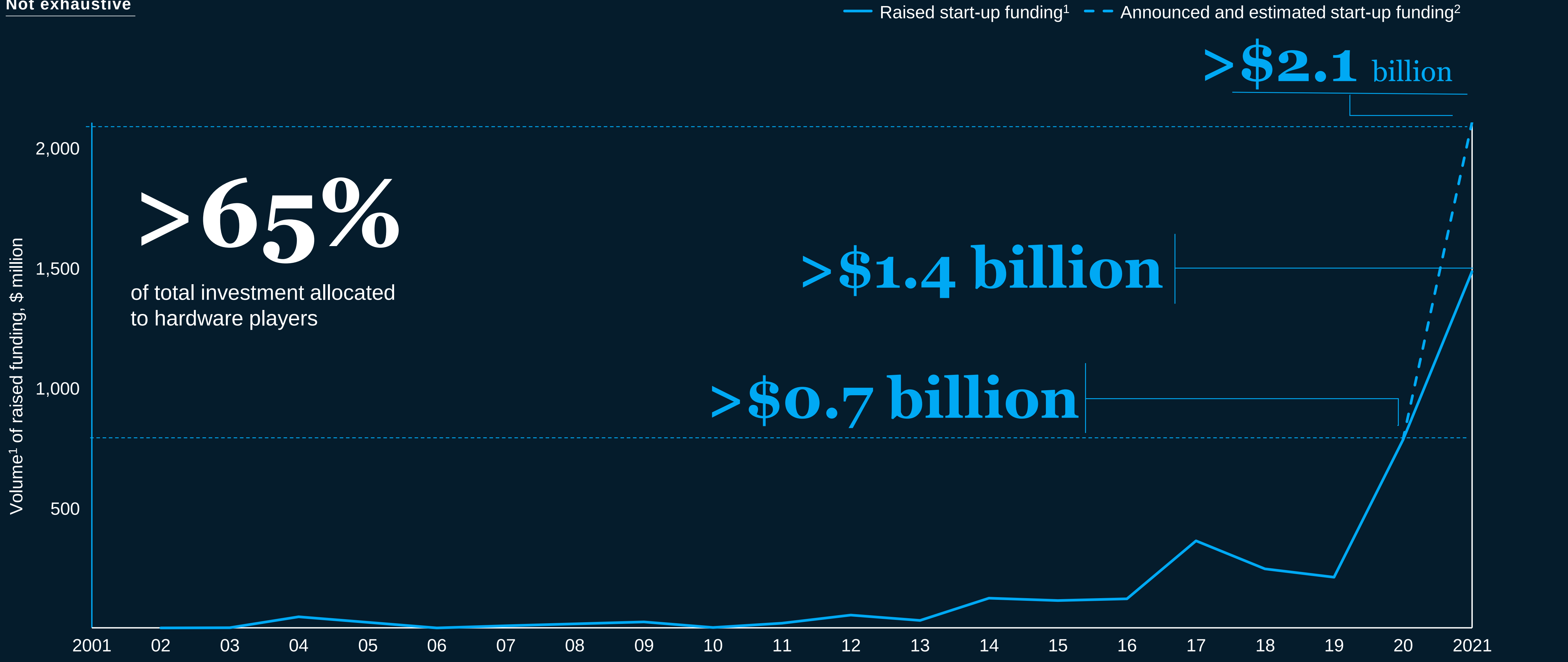
1. Includes start-ups and incumbents that develop or offer QT products; see methodology page for details. Companies that develop products for multiple QTs are included in all relevant categories.
2. Based on public investments in start-ups recorded on Pitchbook and announced deals from 2001 to 2021. Actual investment is likely higher, excludes investments in internal QT departments or projects by incumbents.
3. Exchange rate for market estimates EUR to USD: 1.19.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

The investor landscape

QT start-up investment activity surpassed $1.4 billion in 2021, more than double that of 2020…

Not exhaustive

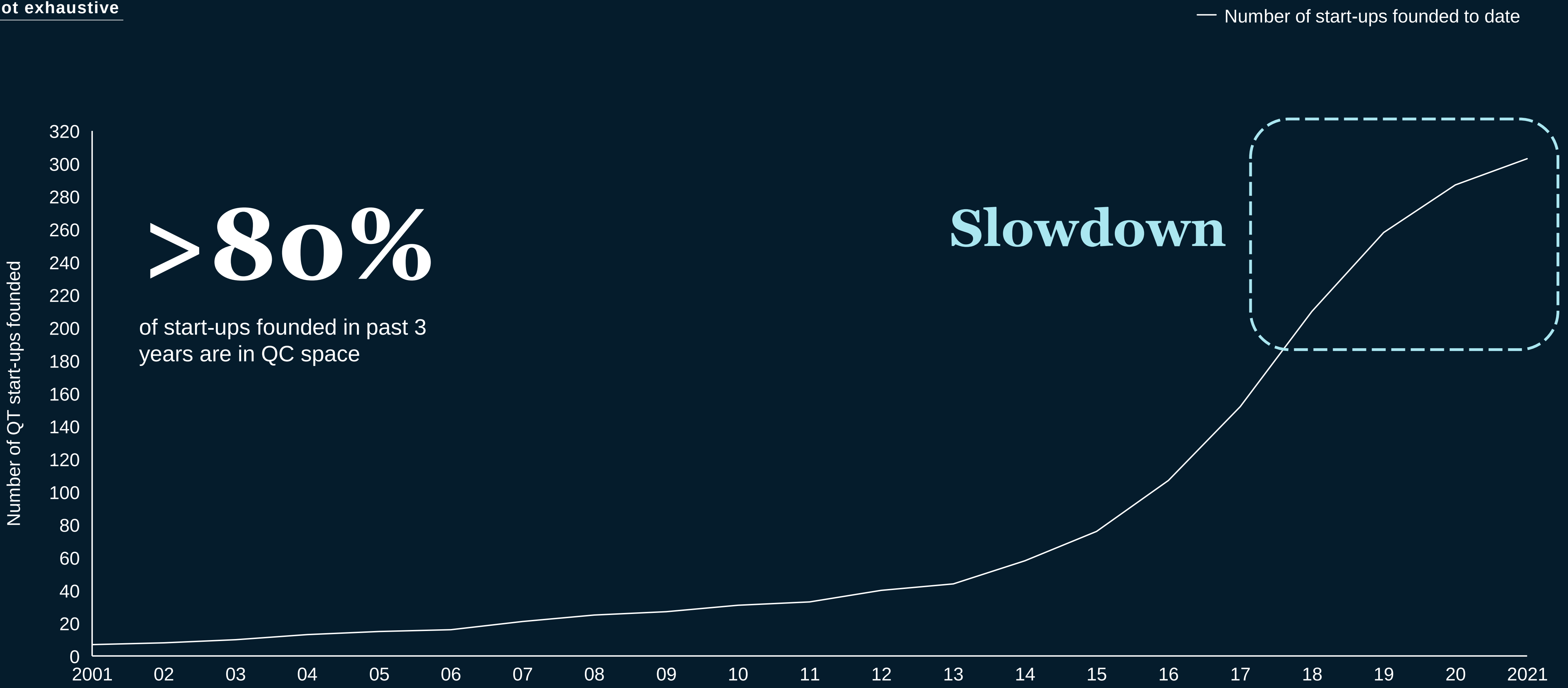


1. Based on public investment data recorded in PitchBook; actual investment is likely higher.
2. Public announcements of major deals; actual investment is likely higher as for 7 out of 20 deals done in 2H2021 the deal size was not disclosed.

Source: PitchBook; McKinsey analysis

…However, the rate of QT start-up founding has slowed in the past three years.

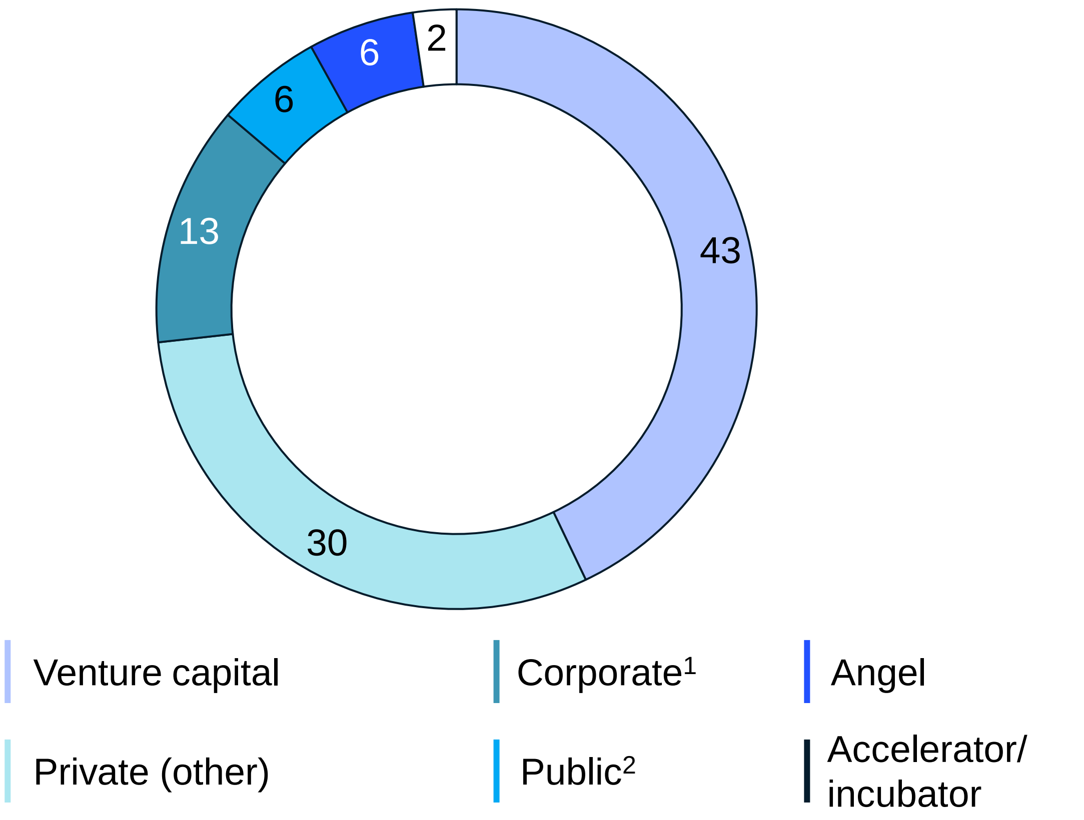
Not exhaustive



Source: Crunchbase; PitchBook; McKinsey analysis

Venture capital and other private capital now make up more than 70 percent of QT investments

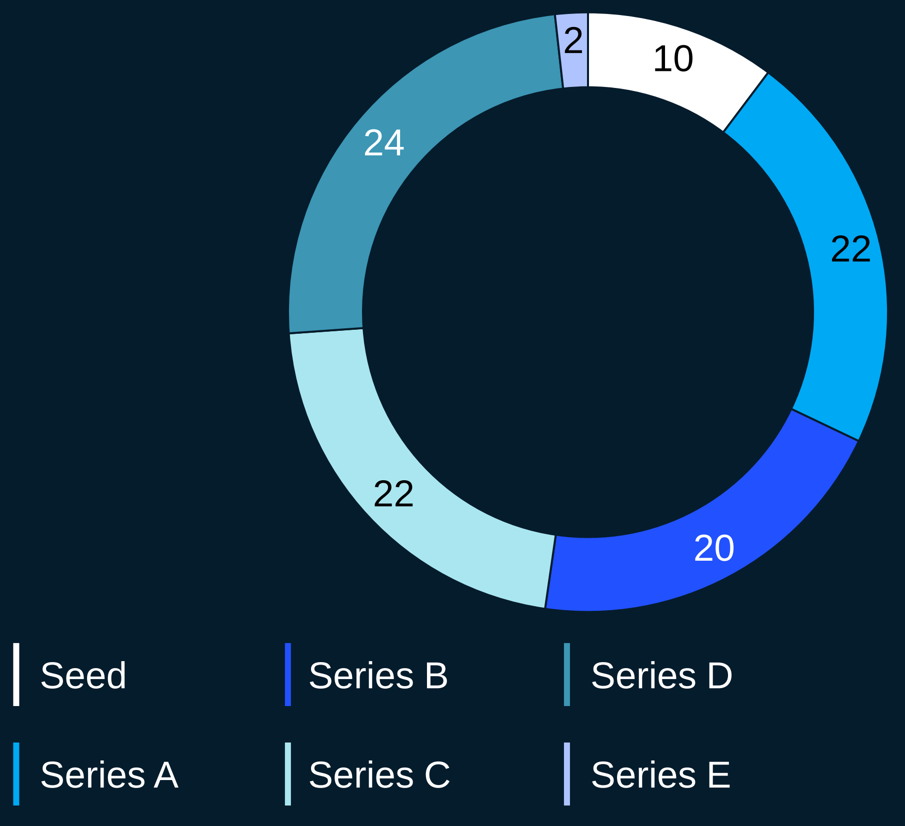
Split of investments, by investor type, 2001–21
(% of total investment value)



1. Includes corporations, corporate venture capital, venture-capital-backed companies, and private-equity-backed companies investing in an external start-up; does not include corporations investing in internal QT programs.
2. Includes governments, sovereign wealth funds, and universities.

Nearly 90% of funding is directed at established start-ups (Series A, B, C, and D)

Split of venture-capital investments, by deal type, 2001–21
(% of total investment value)



Deal size keeps increasing, with the focus still mainly on QC hardware

Top 10 venture-capital/private-equity investments in QT start-ups, ordered by deal size (descending)[1]

Not exhaustive

Quantum computing | Quantum communication | (2021) Deal announced but not yet closed

	Company	Country	Tech	Segment	Deal size, $ million	Deal year	Lead investor
1	PsiQuantum	United States	Quantum computing	Hardware manufacturing	450	2021	BlackRock
2	ArQit	United Kingdom	Quantum communication	Hardware manufacturing	400[2]	(2021)	Centricus Acquisition Corp
3	IonQ	United States	Quantum computing	Hardware manufacturing	350	2021	dMY Technology Group
4	CQC	United Kingdom	Quantum computing	Systems software	300[3]	(2021)	Honeywell
5	PsiQuantum	United States	Quantum computing	Hardware manufacturing	215	2020	Atomico
6	Xanadu	Canada	Quantum computing	Hardware manufacturing	100	2021	Bessemer Venture Partners
7	Rigetti	United States	Quantum computing	Hardware manufacturing	79	2020	Bessemer Venture Partners
8	CQC	United Kingdom	Quantum computing	Systems software	78	2015	Grupo Arcano; Stanhill Capital
9	Silicon Quantum Computing	Australia	Quantum computing	Hardware manufacturing	66	2017[4]	University of New South Wales
10	ID Quantique	Switzerland	Quantum communication	Hardware manufacturing	65	2018[4]	SK Telekom

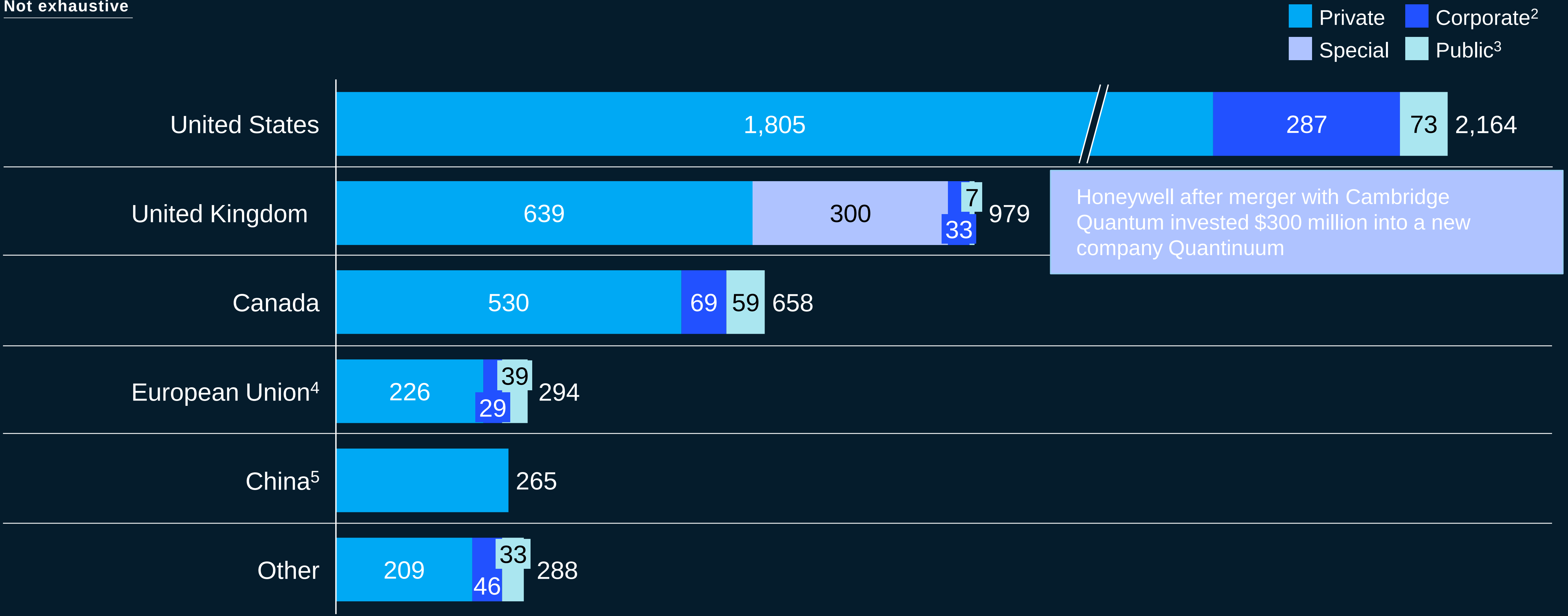
1. Data availability on start-up funding in China is limited. The overview includes all publicly available data on China; however, actual investment is likely higher.
2. Announced but not closed in 2021.
3. Honeywell invested $300 million into a new company Quantinuum.
4. No large investment rounds since; multiple hypotheses on the reason: Silicon Quantum Computing is improving their technology before the next round, ID Quantique creates sufficient revenue from sales and is preparing for an IPO.

Source: Crunchbase; PitchBook; press search; McKinsey analysis

Majority of investments are still in US companies, driven primarily by private investors.

Size of deals in QTs, by primary investor type, 2001–21, $ million[1]

Not exhaustive



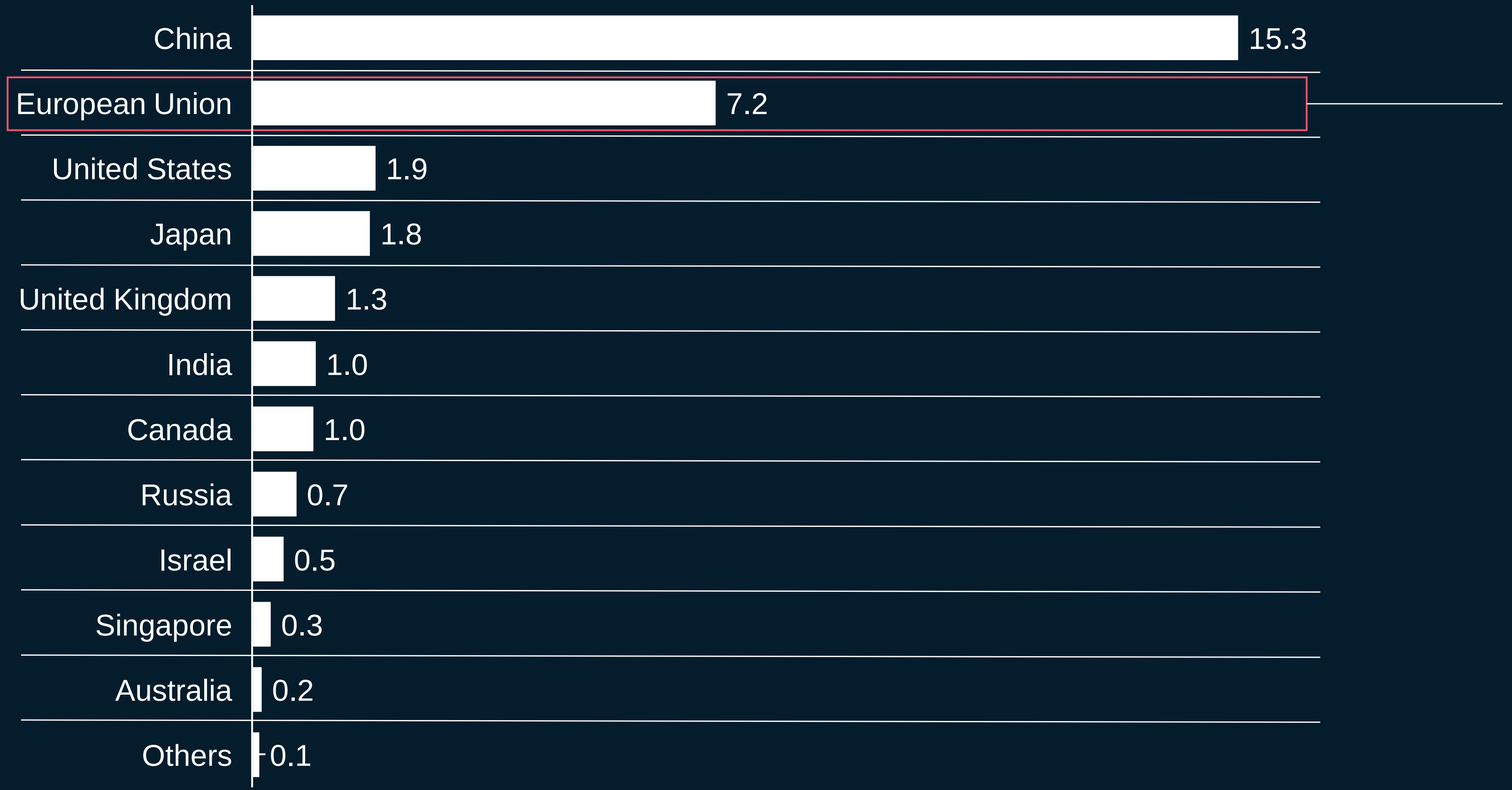
1. Based on PitchBook data; includes announced deals for IonQ, Arqit, Cambridge Quantum Computing, and PsiQuantum. ArQuit deal did not finalize in 2021.Actual investment volume in QTs is likely higher.
2. Includes investments from corporations and corporate venture capital in external start-ups. Excludes corporate investments in internal QT programs.
3. Includes investments by governments, sovereign wealth funds, and universities.
4. Includes European Union, Norway, and Switzerland.
5. Data availability on start-up funding in China is limited. The overview includes all publicly available data on China. While actual investment is likely higher, we think that at this stage most funding awarded by China is to research institutions. Some of the sources estimate that total private investments to be around $615 million.

Source: ICV Thinktank; IT橘子; PitchBook; McKinsey analysis

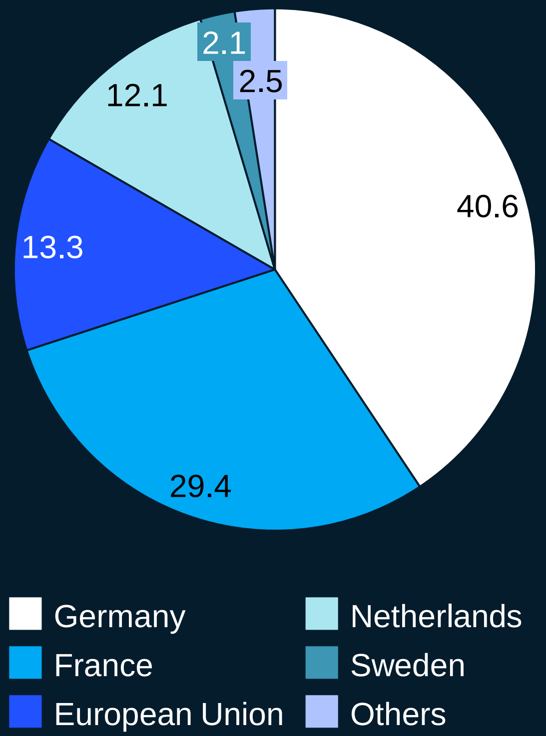
China and the European Union have announced the most public funding planned for QC efforts; Germany has announced most in EU.

Not exhaustive

Announced planned governmental funding[1]
$ billion



EU public funding sources, %



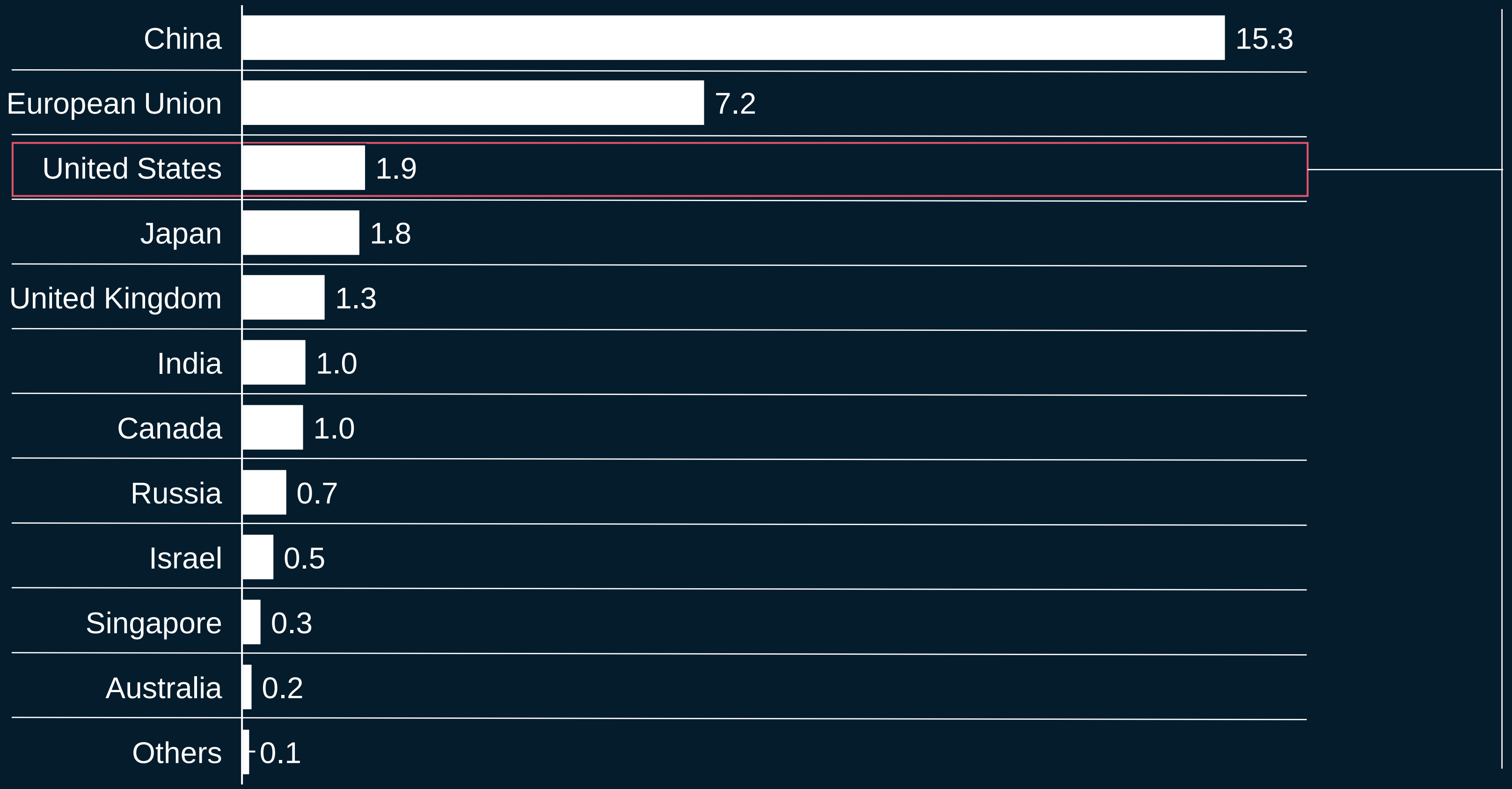
1. Total historic announced funding; timelines for investment of funding vary per country.

Source: Johnny Kung and Muriam Fancy, *A quantum revolution: Report on global policies for quantum technology*, CIFAR, April 2021; press search June 2021

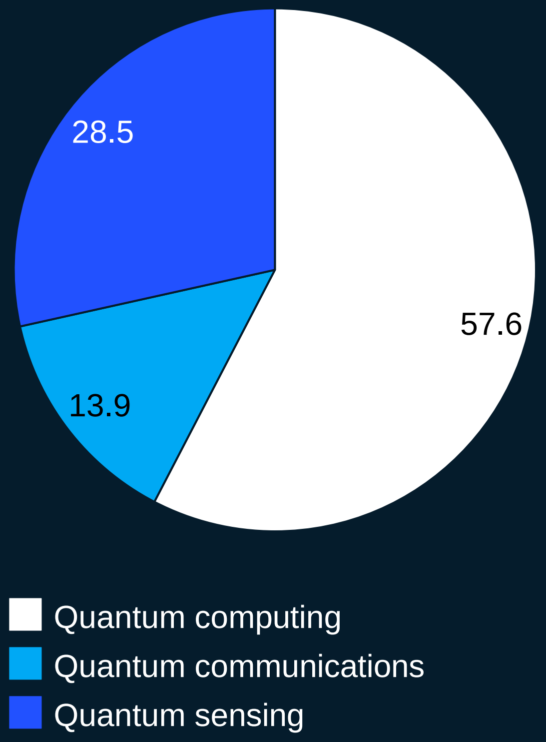
The US government funds more QC efforts than it does QComms or QS.

Not exhaustive

Announced planned governmental funding[1]
$ billion



US public funding split by technology,
%



1. Total historic announced funding; timelines for investment of funding vary per country.

Source Johnny Kung and Muriam Fancy, *A quantum revolution: Report on global policies for quantum technology*, CIFAR, April 2021; press search June 2021

Stimulated by government funding, quantum technology activity in China is accelerating.

Preliminary

Figures

~$15 billion
for QT as part of China's 14th five-year plan (2021–25)

~$265 million
of private investments into Chinese QT start-ups

~53%
of QT-related patents were granted to Chinese researchers

12
Dedicated QT research institutions

32
Companies active in QT

Policies

- **2021:** University of Science and Technology of China (USTC) had been authorized to award doctorates in quantum science and technology, the country's first doctoral program in QT
- **2021: Quantum information science** was announced as one of new majors in the catalogue of undergraduate majors in **ordinary colleges and universities**
- **2019:** China announced an education modernization plan that assumes 4% of GDP spend on education and differentiates quantum technology as one of four main areas of focus

News

- **2021:** In January, Chinese scientists have set up an integrated quantum network that combines 700 fiber and two ground-to-satellite links and realized quantum key distribution between more than 150 users over a combined distance of 4,600 kilometers
- **2020:** In December, researchers from the Hefei National Laboratory claimed quantum supremacy with a photonic prototype

Source: IT橘子(ITOrange); press search

Quantum computing

The United States and Canada are still the most active countries in QC, as measured by number of players involved.

Number of QC players, by country

Not exhaustive

+ indicates change in 2H2021

		Start-ups	Incumbent companies	Public/ government organizations	Academic groups
Top 7	United States	60 +1	9	18	64 +1
	Canada	27 +4	0	2	9
	United Kingdom	19	1	2	14 +1
	Japan	13 +1	1	0	7
	France	8	1	3	9
	Germany	8 +1	2	1	7
	China[1]	8 +1	2	12	11
Rest of world		69 +8	1	19	55 +5
Total		**212** +16	**17**	**57**	**176**

1. There is limited transparency on commercial activity in China and to a lesser extent for Japan. We think Chinese activity in QTs is primarily through government-funded research institutions.

Source: Press and web research; McKinsey analysis

QC start-ups continue to emerge across the globe, with the most new launches in the European Union and Canada.

Number of QC start-ups, by country (YE2021 and in 2015)[1]

Not exhaustive

„+" indicates the change in 2H2021

Country	2021		2015
United States	60	+1	16
Canada	27	+4	6
United Kingdom	19		4
Japan	13	+1	3
China	8	+1	0
France	8		0
Germany	8	+1	1
Australia	7	+1	2
Spain	7	+1	0
Finland	6	+1	1
Netherlands	6		1
India	5	+1	0

Country	2021		2015
Switzerland	5		2
Israel	4		0
Austria	2		0
Colombia	2		1
Denmark	2		1
Poland	2	+1	0
Singapore	2		0
Sweden	2		2
United Arab Emirates	2	+1	0
Bulgaria	1	+1	0
Czechia	1		0
Estonia	1		0

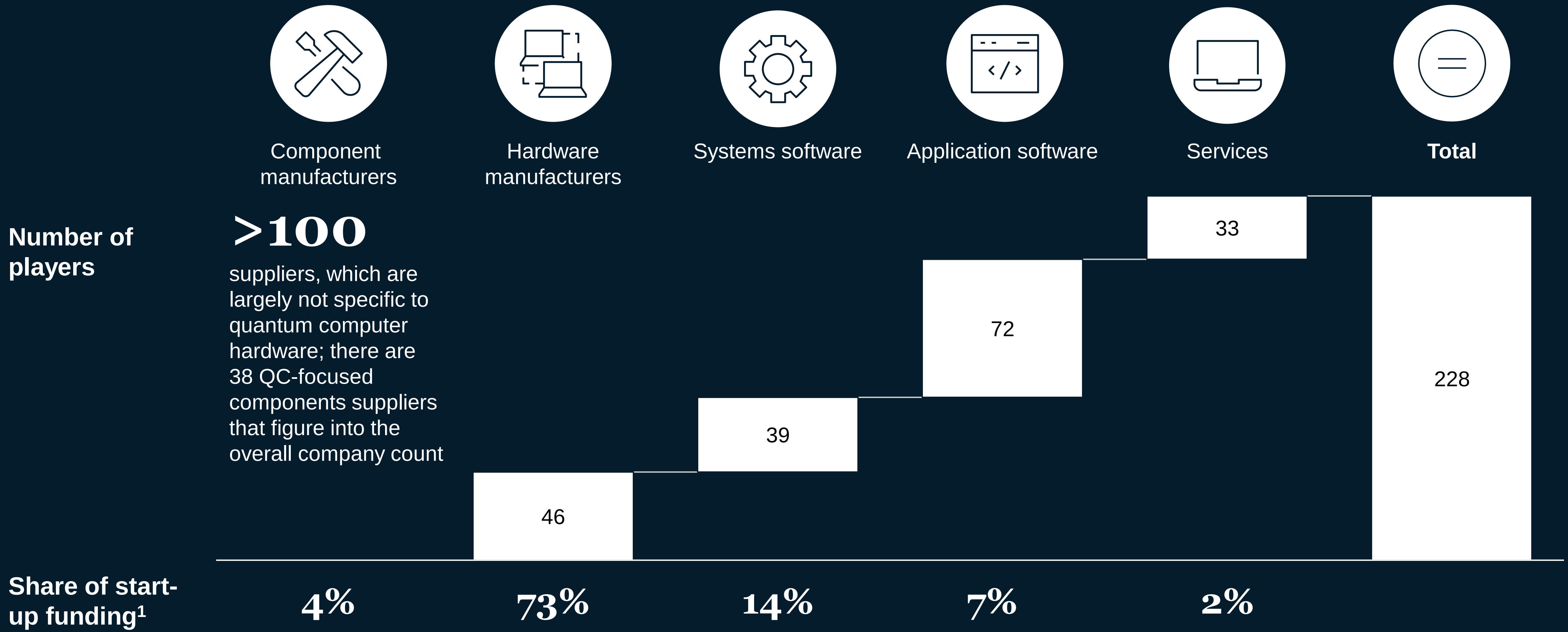
Country	2021		2015
Greece	1		0
Hong Kong	1		1
Italy	1		0
Liechtenstein	1		0
Philippines	1	+1	0
Norway	1		1
Portugal	1		0
Romania	1		0
Russia	1		1
Taiwan	1		0
Turkey	1		1
Uruguay	1		0
Grand total	**212**	+16	**44**

1. There is limited transparency on commercial activity in China and to a lesser extent for Japan. We think Chinese activity in QTs is primarily through government-funded research institutions.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Most players are component and application software companies, but hardware start-ups still get the biggest share of funding.

Number of QC players, by value chain segment[1]

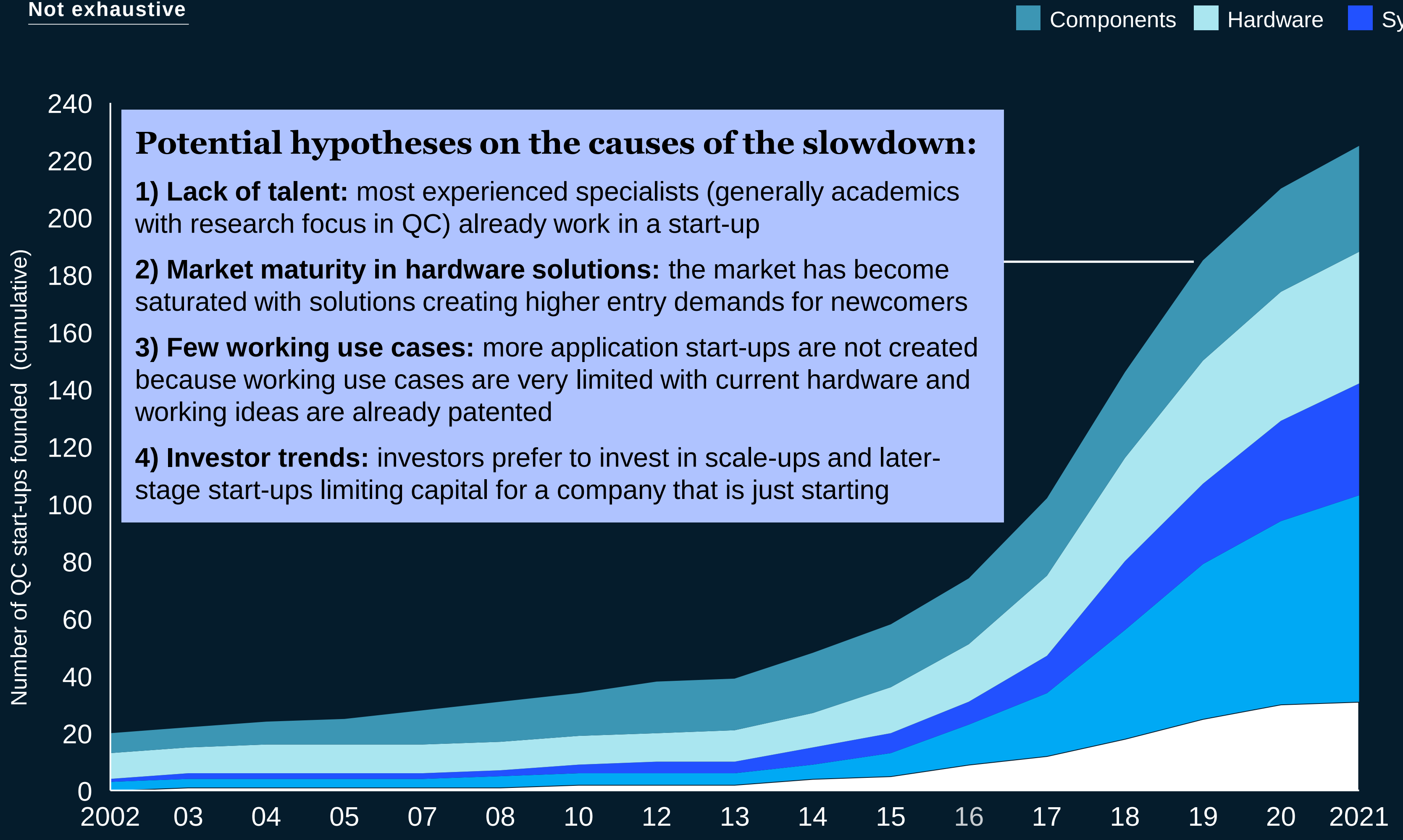


1. Includes start-ups and incumbents that develop or offer QT products; see methodology pages for details.
2. Based on public investments in start-ups recorded on PitchBook and announced in the press; includes announced deals for 2021; excludes investments in internal QT departments or projects by incumbents; actual investment is likely higher.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

The rate of publicly announced QC start-up founding has slowed over the past three years.

Not exhaustive



Potential hypotheses on the causes of the slowdown:

1) Lack of talent: most experienced specialists (generally academics with research focus in QC) already work in a start-up

2) Market maturity in hardware solutions: the market has become saturated with solutions creating higher entry demands for newcomers

3) Few working use cases: more application start-ups are not created because working use cases are very limited with current hardware and working ideas are already patented

4) Investor trends: investors prefer to invest in scale-ups and later-stage start-ups limiting capital for a company that is just starting

Number of QC companies founded in

2018	2019	2020	2021
3	5	1	1
8	7	2	1
11	4	7	4
16	16	10	8
6	7	5	1

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

The QC ecosystem spans hardware and software.

The **core parts** of the QC ecosystem do not have commercial products yet. Revenue is generated mainly through component players, consulting services, and joint research projects[1]

Mature market	Developing markets			
Equipment/ components	**Hardware**	**Systems software**	**Application software**	**Services**
The components segment is the most mature, yet there is room for specialized players	Hardware is dominated by big tech players, who mostly focus on superconducting qubits	The systems software market is split between full-stack and dedicated software players	Application software is immature and far from saturated; players focus on a few key industries	The services segment is split between consulting services and cloud services

1. Funding/revenue ranges defining maturity: more than \$100m is high, \$1m–\$100m is medium, \$10,000–\$1m is low, and less than \$10,000 is very low/unknown.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Not exhaustive

The components segment is the most mature, yet there is room for specialized players

Mature market **Developing markets**

The components segment is generating revenue

- The components segment is the only segment of the QC value chain that is generating significant revenue through sales to universities, research institutes, and technology companies.
- Players range from specialized QT players to general technology manufacturers (eg, electronics), scattered across a range of technologies.
- Product maturity varies per component, yet nearly all components still require customization by quantum players.

Technology challenges offer room for new entrants

- Technology improvement is needed across component types to enable scaling to fault-tolerant QC. This leaves room for specialized players to enter the market.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Not exhaustive

Hardware is dominated by big tech players and a few scale-ups, with most capital in superconducting qubits

Mature market **Developing markets**

Big tech players benefit from high entry barriers within hardware

- Due to the complexity of the technology, the hardware segment has high risk and long development times. As a result, players require significant capital and highly specialized knowledge. The hardware segment today is dominated by technology giants, most of which entered the market a decade ago and focus on superconducting qubits.

Start-ups focused on various qubit technologies are scaling up

- Recently, few start-up companies in ion traps and photonic qubits have raised significant funding and are scaling up.
- Based on public announcements, superconducting qubits are the most developed, yet some experts believe photonic qubits are technologically ahead.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

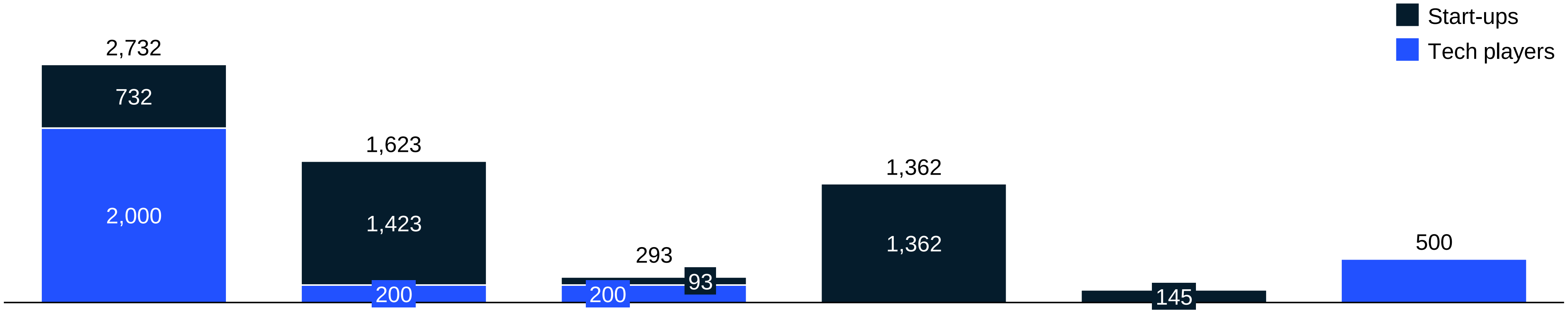
Technology giants dominate in superconducting qubits; start-ups are catching up on trapped ions and photonic networks.

Non-exhaustive

Preliminary

Technology	Superconducting circuits	Trapped ions	Spin qubits	Photonic networks	Neutral atoms	Majorana fermions
Qubit description	Difference in Cooper pairs between two islands of a Josephson tunnel junction	Internal energy levels of ions trapped by electromagnetic fields	Electron spin of one electron localized in a semiconductor quantum dot or insulator defect (eg, NV centers in diamond)	Occupation of a photonic waveguide	Internal energy levels of highly excited atoms trapped by laser fields	Two Majorana modes at superconductor/ semiconductor interfaces
Maturity						

Funding ($m)



1. Assumptions: $500m per strongly invested player (Alibaba, AWS, Google, IBM, Microsoft), $200m per moderately invested player (Honeywell before merger with CQC, Intel).

Source: Crunchbase; Capital IQ; PitchBook; Quantum Computing report; expert interviews; team analysis

Not exhaustive

The systems software market is split between full-stack and dedicated software players; most products are in prototype phase

Mature market **Developing markets**

The systems software market is split between full-stack and dedicated software players

- Systems software players offer logical programming languages for quantum computers as well as compilers and error-correction software. Some systems software players offer dedicated control software for quantum hardware.
- The systems software market is divided between leading full-stack players, who offer programming languages for their own hardware, and dedicated software players offering hardware-agnostic solutions.

Most products are in the prototype phase

- Leading systems software solutions are available in prototype form, mostly open source. Existing solutions are suitable for the small-scale quantum hardware available today and require further development to support large-scale, fault-tolerant quantum computers.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Not exhaustive

Despite a large number of players, application software is immature and far from saturated

Mature market | **Developing markets**

Despite a large number of players, application software is immature

- The application software market has emerged in the past few years. Key players are hardware and systems software players offering full-stack solutions. They operate across all industries, or focus on finance, pharmaceuticals, and chemicals. Start-ups focusing on a specific solution or industry have emerged in recent years.
- Off-the-shelf products do not yet exist; most business models are still based on exploratory research projects in collaboration with industry.

The market is still far from saturated

- The development of end-to-end quantum solutions for business problems still takes years; due to the wide range of potential quantum applications in various industries, the application software market is far from saturated.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Not exhaustive

The services segment is split between consulting services and cloud services

Mature market | **Developing markets**

Cloud services form a key part of the QC services segment

- The cloud services market is in an early stage of development. Players offer public access and premium computing time on existing hardware for education and experimentation. Cloud players are split between upward integrating hardware players and dedicated cloud players offering access to third-party hardware. Significant growth of this segment is expected once quantum hardware matures.

Consulting services and research

- Consulting services and joint research projects are a key source of income for hardware and software players. In addition, there are few dedicated consulting players as well as players offering QC education and media.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Quantum communications

QComms start-ups continue to rise across the globe, with most in the United States and the European Union.

Number of QComms start-ups, by country (YE2021 and in 2015)[1]

Not exhaustive

Country	2021	2015
United States	19	5
China	16	6
United Kingdom	15	4
Canada	8	3
France	4	1
Germany	3	1
Netherlands	3	1
Switzerland	3	2
Australia	2	1
India	2	0
Japan	2	1
Poland	2	0

Country	2021	2015
Singapore	2	0
Spain	2	0
Bulgaria	1	0
Colombia	1	0
Finland	1	1
Israel	1	0
Russia	1	1
South Korea	1	1
Grand total	**89**	**28**

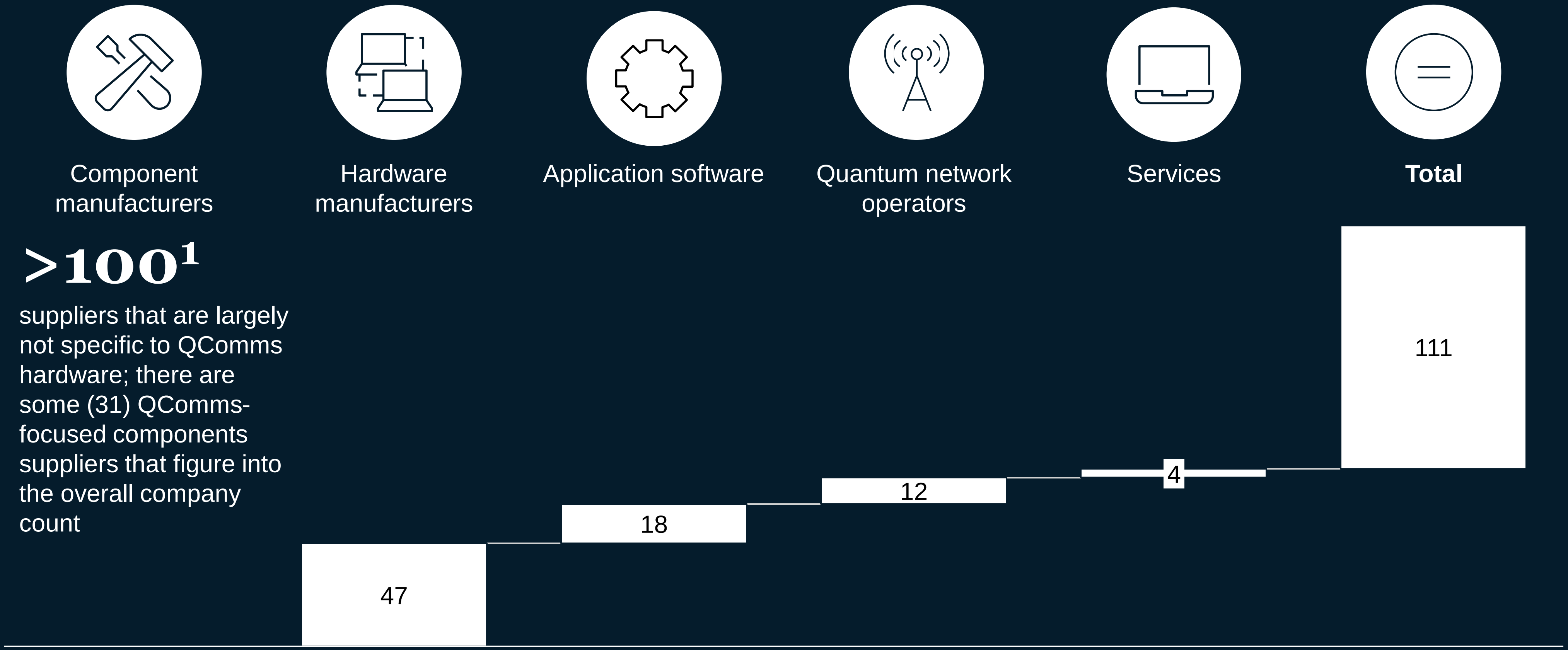
1. There is limited transparency on commercial activity in China and to a lesser extent for Japan. We think Chinese activity in QTs is primarily through government-funded research institutions.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Most funding is raised for application software start-ups, despite their relatively small number.

Number of QComms players, by value chain segment[1]

Number of players



Share of start-up funding[2]	Component manufacturers	Hardware manufacturers	Application software	Quantum network operators	Services
	11%	36%	53%[3]	—	0%

1. Includes start-ups and incumbents that develop or offer QT products; see methodology pages for details.
2. Based on public investments in start-ups recorded on PitchBook and announced in the press. Includes announced deals for 2021; excludes investments in internal QT departments or projects by incumbents. Actual investment is likely higher.
3. Application software funding is driven by large deal ($400m) for Arqit (United Kingdom) to develop quantum satellite communication.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

The **core parts** of the QComms ecosystem **(hardware and software)** do not have commercial products yet. Revenue is generated mainly through component players, consulting services, and joint research projects[1]

1. Funding/revenue ranges defining maturity: more than $100m is high, $1m - $100m is medium, $10,000–$1m is low, and less than $10,000 is very low/unknown.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

The QComms ecosystem is dominated by large technology players.

Overview of QComms players

Mature market	Developing markets			
Equipment/ components	**Hardware**	**Application software**	**Quantum network operators**	**Services**
The equipment/ components segment is split between general component suppliers and specialized QT players	Big global players have entered the hardware segment of the QComms market, yet medium-size start-ups are technologically more advanced. Partnerships are formed to bridge the gap	The application software market is relatively immature. Various start-ups are scaling up	Various telecommunications providers have started to invest in QComms; these are likely to fulfill the role of quantum network operators in the future	Few consulting services players of low maturity have entered the market; their focus is primarily on security, or QT in general.

Quantum sensing

The number of QS players has nearly doubled over the past five years; however, their numbers remain comparatively low.

Number of QS start-ups, by country (YE2021 and in 2015)[1]

Not exhaustive

Country	2021	2015
United States	13	8
Switzerland	5	2
France	4	2
Germany	4	3
United Kingdom	4	2
China	3	1
Netherlands	3	1
Denmark	2	2
Australia	1	0
Canada	1	0
Finland	1	1
Japan	1	1

Country	2021	2015
Singapore	1	0
Sweden	1	1
Turkey	1	1
Grand total	**45**	**25**

1. There is limited transparency on commercial activity in China and to a lesser extent for Japan. We think Chinese activity in QTs is primarily through government-funded research institutions.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Overall investment in QS is still low, with the majority of players and funding focused on components.

Number of QS players, by value chain segment[1]

	Component manufacturers	Hardware manufacturers	Applications and services	Total number
Number of players	**>100[1]** suppliers, which are largely not specific to QS hardware; there are a few (39) QS- focused components suppliers that figure into the overall company count	16	13	58
Share of start-up funding[2]	**51%**	**21%**	**28%**	

1. Includes start-ups and incumbents that develop or offer QT products; see methodology pages for details.
2. Based on public investments in start-ups recorded on PitchBook and announced in the press. Includes announced deals for 2021; excludes investments in internal QT departments or projects by incumbents; actual investment is likely higher.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

The QS market is still in the prototype stage.

Non-exhaustive

The **core parts** of the QS ecosystem **(hardware and software)** do not have commercial products yet. Revenue is generated mainly through components players, consulting services, and joint research projects[1]

Mature market

Equipment/ components

The components segment of the QS market is most mature; manufacturers sell commercial products, but push-button solutions do not yet exist

Developing markets

Hardware

Hardware products are mostly at the level of prototypes. They require optimization in price, size, and weight to become competitive beyond niche markets

Application software and services

The application software and services segment has few players; it is expected to grow as hardware matures

1. Funding/revenue ranges defining maturity: more than $100m is high, $1m–$100m is medium, $10,000–$1m is low, and less than $10,000 is very low/unknown.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Industry adoption of quantum computing

Quantum computing will likely affect chemicals, pharmaceuticals, automotive, and the financial industry in the near term.

Illustrative

Horizons: Primary value pools

Economic value: Incremental, Significant, Disruptive

Economic value ($ trillion)

Industry	Key segment for QC	Impact of QC[1] ~2025–30	Impact of QC[1] ~2030–35	Industry size
Global energy and materials	Oil and gas	Incremental	Significant	5–10
	Sustainable energy	Significant	Disruptive	1–5
	Chemicals (primary value pool)	Significant	Disruptive	1–5
Pharmaceuticals and medical products	Pharmaceuticals (primary value pool)	Significant	Disruptive	1–5
Advanced industries	Automotive and assembly (primary value pool)	Incremental	Significant	1–5
	Aerospace and defense	Incremental	Significant	<1
	Advanced electronics	Incremental	Significant	<1
	Semiconductors	Incremental	Significant	<1
Financial industry[1]	(primary value pool)	Incremental	Significant	>10
Telecommunications, media, and technology	Telecommunications	Incremental	Significant	1–5
	Media	Incremental	Incremental	1–5
Travel, transport, and logistics	Logistics	Incremental	Significant	5-–10
Insurance		Incremental	Incremental	5–10

1. Relative impact on the industry; absolute impact depends on relative impact as well as the size of the industry.
2. Includes asset management.

Source: Industry reports; McKinsey Technology Council; McKinsey analysis

Outlook

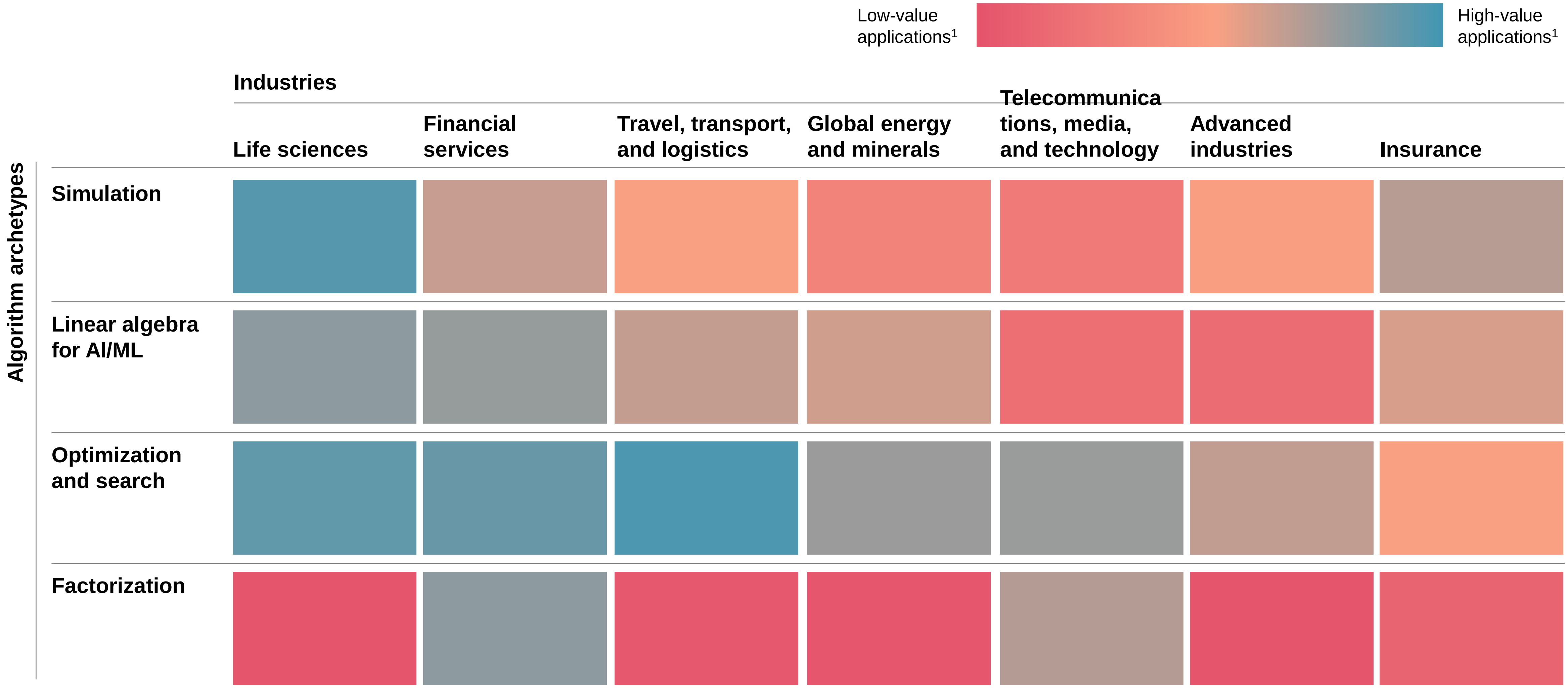
Impact from QC is expected to be most disruptive for the chemicals and pharmaceutical industries, as QC-based simulation of molecular processes may replace the need for lab-based testing.

In the automotive industry, this may stimulate breakthroughs in battery development and new fuels.

Impact on the financial industry is more incremental, yet the value at stake is high, especially in asset management.

However, the highest-value use cases will likely be in the life sciences and financial services sectors over the long term.

Qualitative estimate of expected value unlocked by the application of QC



1. By 2030.

Global technology progress

China increased its quantum-related patent activity across all technologies.

Share of quantum patents by company's HQ country, 2000–21,[1] %

Preliminary

		QC	QComms	QS
China	53.8	54.1	46.2	59.7
Japan	15.2	15.4	18.4	14.8
European Union	11.2	11.5	10.0	14.8
United States	10.0	9.6	6.5	4.5
South Korea	4.0	3.9	6.2	3.4
Taiwan	1.8	1.8	4.5	2.3
United Kingdom	1.2	1.0	3.4	0
Canada	0.8	0.6	1.6	0
Switzerland	0.6	0.6	1.0	0
Russia	0,6%	0,6%	0,5%	0%

1. Only 50% of headquarters for patent applications are disclosed.

Source: Innography; expert interviews; McKinsey analysis

Key takeaways

China has increased its share of patents in recent years, accross all technologies, which is influenced highly by Chinese government policies.

Japan has been among the top 3 in QT patent development since the early 2000s. Japan's high share of QT patents indicates a high degree of QT industry adoption.

The United States and the European Union had the highest number of patents in QT until ~2005, then this number started declining due to changes in culture around intellectual property.

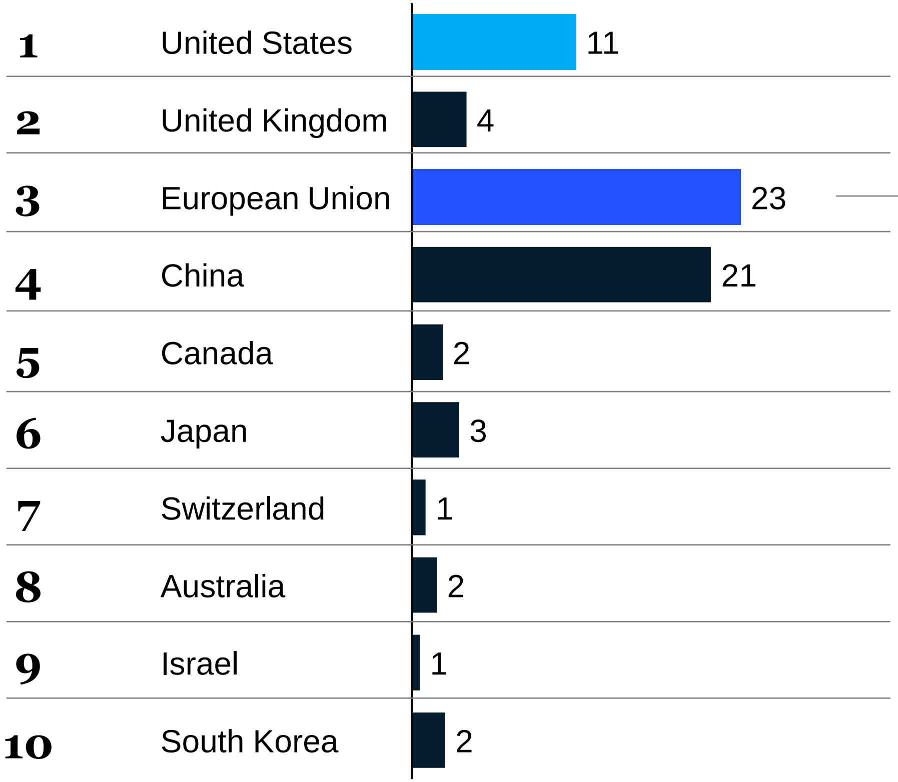
The European Union publishes the most on quantum topics, but the United States leads in impact of published material.

As of 2020 (update coming in next release)

XX Rank of country's h-index

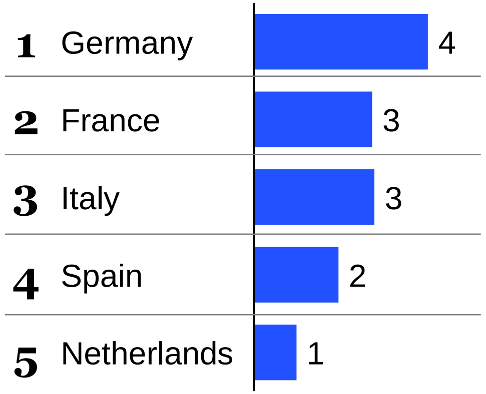
Top 10 countries worldwide 2020, by h-index

Share of articles and country's h-index[1] in quantum-relevant publications,[2] %



Top 5 EU countries

Share of articles and h-index, 2020, %



Key takeaways

US publications have the **highest impact** as measured by h-index, indicating a leading position in academic research.

The European Union is leading in terms of **published articles** in 2020 in quantum-relevant fields, followed by China and the United States.

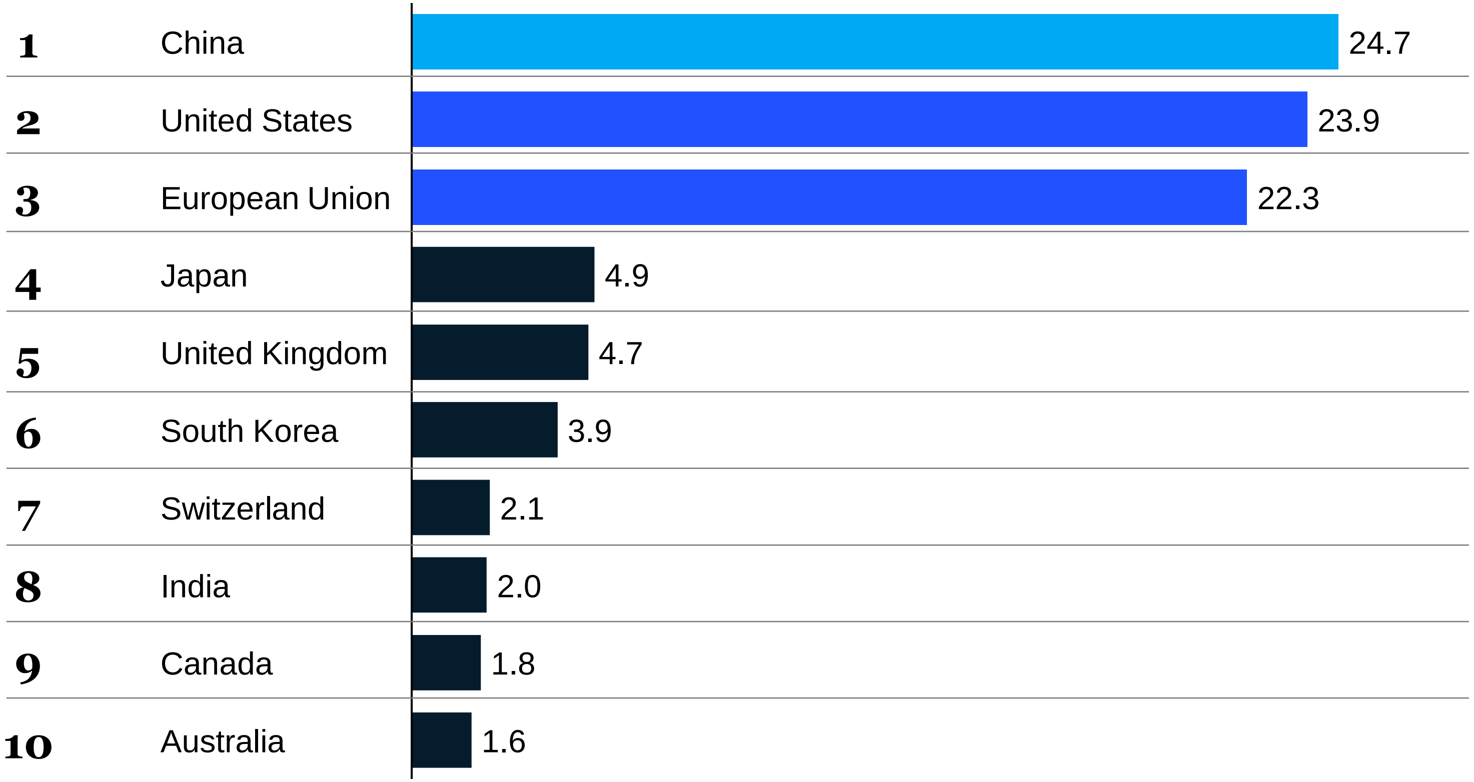
1. The h-index is the number of articles (h) in a country that have been cited at least h times.
2. Quantum-relevant publications defined as publications in information and communications technology, mathematics and statistics, and physics.

Source: SCImago Journal & Country Rank; McKinsey analysis

However, scientists from Chinese research institutions contribute to quantum-relevant publications most often.

Top 10 countries worldwide 2021, by share in scientific publications

Share of authors from country's research institutions contributing to quantum-relevant publications,[1] %



1. Quantum-relevant publications defined as publications in physical sciences.

Source: Nature Index; McKinsey analysis

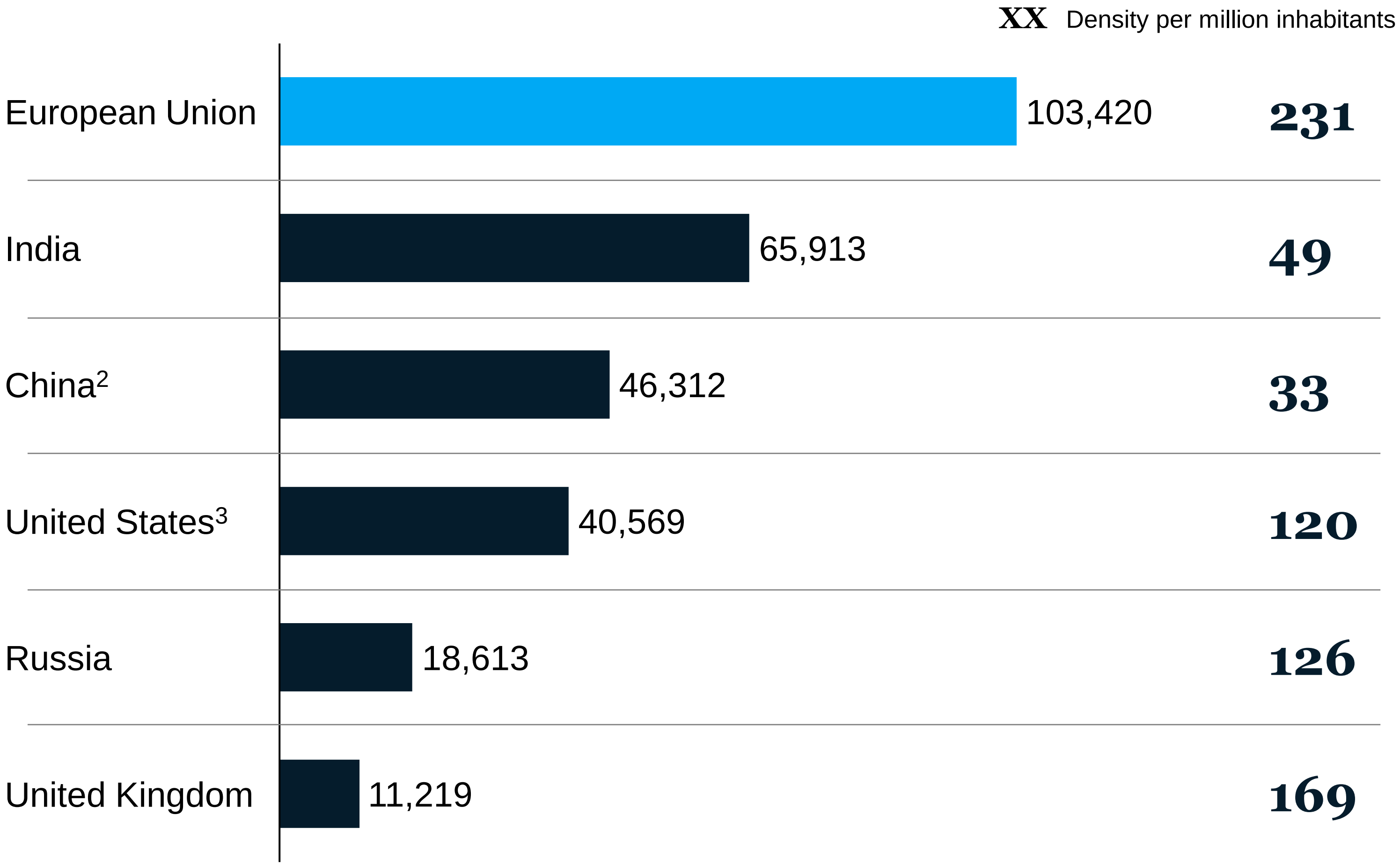
Key takeaways

Scientists affiliated with Chinese institutions contribute to almost a quarter of quantum-relevant academic publications.

Researchers affiliated with US and EU institutions round out the top 3 and account for about 24% and 22% of contributions to quantum-relevant publications, respectively.

The European Union has the highest concentration of QT talent.

Absolute number of graduates in QT-relevant fields,[1] 2019



1. Graduates of master's level or equivalent in 2019 in biochemistry, chemistry, electronics and chemical engineering, information and communications technology, mathematics and statistics, and physics.
2. High-level estimates.
3. The actual talent pool for the United States may be larger, as bachelor programs are longer and master's programs are less common.

Source: National government websites; OECD; McKinsey analysis

Key takeaways

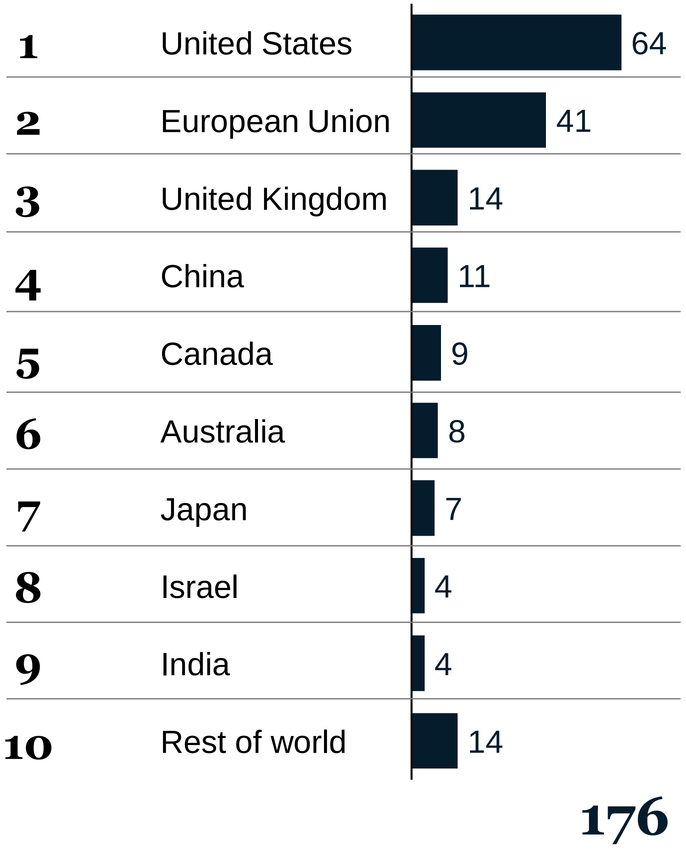
The highest number of **QT-relevant graduates is educated in the European Union,** followed by India and China.

The European Union also has the highest concentration of **quantum-relevant talent,** followed by the United Kingdom and Russia.

Few universites offer advanced degree programs in QT.

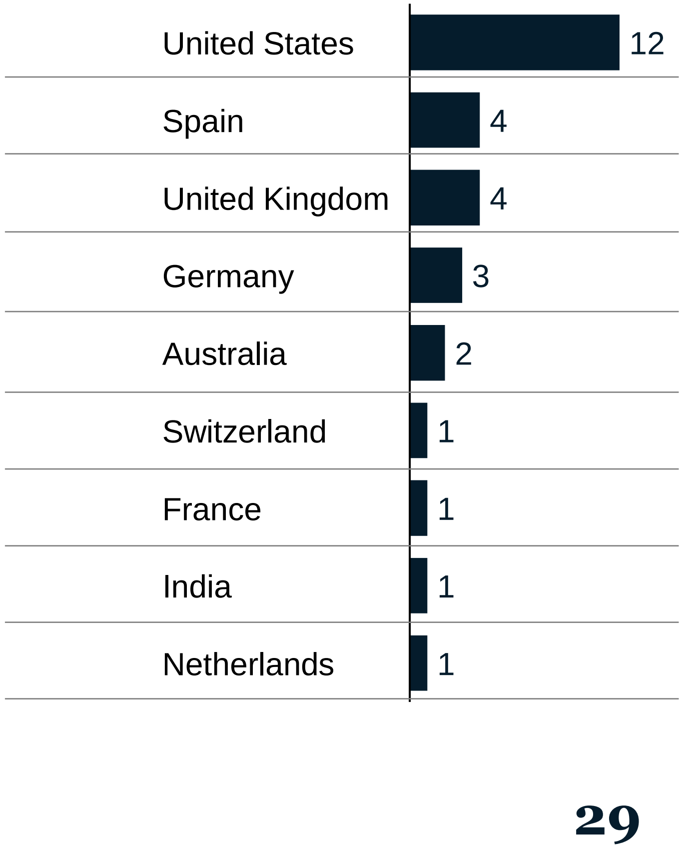
Top 10 countries worldwide 2021, by number of universities with QT research programs

Number of universities per country



2021 universities with QT master's degree offering

Number of universities per country

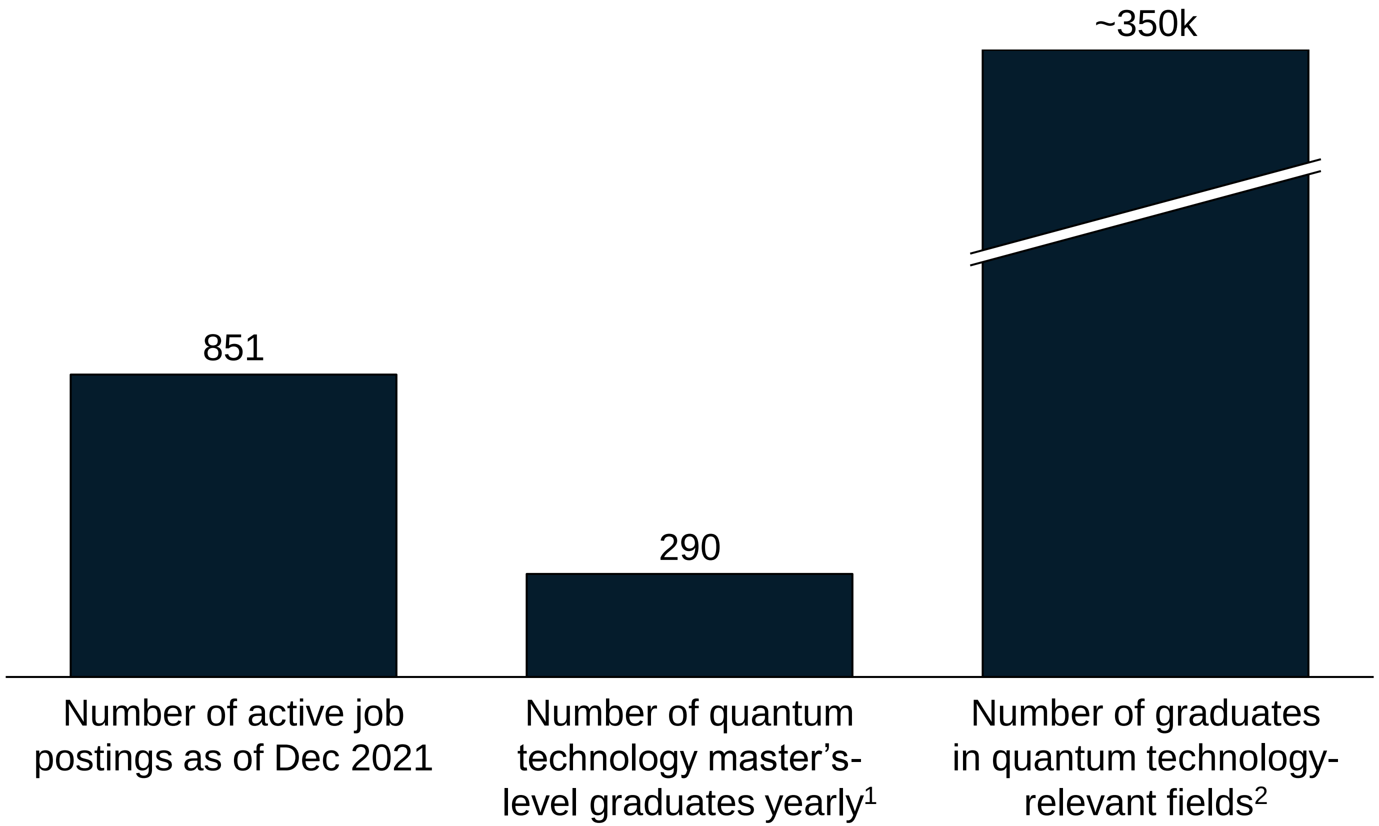


Key takeaways

- There is already a significant number of universities with quantum research programs (176), but not many of them (29) offer master's degrees in QT yet.
- Universities generally recognize the need of the industry for QT specialists but are slower to develop programs to satisfy it.
- US universities account for over a third of all universities with QT research programs.

Source: Web search; McKinsey analysis

The talent gap for QC jobs could be addressed with upskilling programs.



Key takeaways

- There were 851 open positions for QC jobs as of December 2021.
- In comparison, there are only ~290 graduates yearly that are ready to fill in a position requiring QT skills with little training; only about a third of the market demand can be met.
- There could be big potential for upskilling programs as ~350k people graduate with some QT-relevant knowledge.

1. Estimate based on the number of universities with such programs and how many students graduate per year.
2. Graduates of master's level or equivalent in biochemistry, chemistry, electronics and chemical engineering, information and communications technology, mathematics and statistics, and physics.

Source: OECD; Quantum Computing Report.

Where is quantum headed?

- The race for technological leadership in QC is still undecided; most players have invested in photonic, trapped-ion, spin, and superconducting qubit devices
  — Various players aim to gradually improve their hardware technology and manufacture large-scale quantum computers for commercial applications by 2030
- While the United States and Canada have been market leaders for the last decade, China and the European Union are determined to catch up and have announced significant public funding
- More players across industries will move from precompetitive explorations of QC into competitive research (partly in “stealth mode”)
- In QComms and QS, many products will move from the prototype stage to commercialization; this will likely lead to an increase in application and services players
- Several large investment rounds have already been announced for 2021 (eg, IonQ, ~$650m; ArQit, ~$345m; Cambridge Quantum Computing, ~$300m; Xanadu, ~$100m), suggesting that the investment activity around QC will continue to grow
- Chinese researchers made a claim to quantum supremacy (for a boson-sampling problem) in December 2020, and local research is expected to yield more breakthrough results backed by government funding for QC

Methodology

Methodology

Quantum technology player landscape, investments, and market sizing

- To obtain the QT player landscape, we considered the following:
  - Start-ups: founded in the past 25 years, with estimated revenues below $200m
  - Incumbent companies: companies with revenues above $200m
  - Component manufacturers are considered as such if they develop components specifically for QT; general technology component suppliers are excluded
  - Hardware manufacturers are considered as such if they have already demonstrated the creation of a quantum computer or have announced efforts in this direction
  - Telecommunications companies are considered as such if they invest in QComms to become a quantum network operator
  - Relevant general technology components suppliers are included in the ecosystem, but not in the overall count of QT players; the same holds for quantum media companies and quantum education providers
- Investments in start-ups have been extracted from PitchBook and amended by McKinsey analyses[1]
- Market sizes have been calculated across three scenarios (low, base, high) that consider different hypotheses for the spread of use of QC, QComms, and QS, as well as the speed at which technological challenges are resolved

1. Total funding for start-ups focusing on multiple technologies is shown for each technology separately, but not double-counted in the overall QT funding.

Authors

Niko Mohr
Partner
Düsseldorf

Mateusz Masiowski
C&I Analyst
Wroclaw

Matija Zesko
C&I Specialist
Zürich

Henning Soller
Partner
Frankfurt

McKinsey & Company