McKinsey & Company

The Quantum Technology Monitor

Facts and figures

September 2021

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What is this document[1] for?

- Continuously evolving overview of the **global QT player and investment space,** updated biannually
- Dynamic overview of industries' **maturity toward QT (QT),** based on the current application of the technology and application of patents

What it is not

- **Definitive and exhaustive list** of the start-up and funding activities in the QT realm

1. The Quantum Technology Monitor is based on research from various data sources (eg: CapitalIQ, Crunchbase, Pitchbook, press search, Quantum Computing Report, Expert interviews, McKinsey analysis. Minor data deviations may exist due to updates of the respective databases

Three main areas of QT-QC, QS, quantum communication-enable new capabilities across industries

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 (e.g., gravity, time, electromagnetism) that are orders of magnitude more sensitive than classical sensors

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

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 'eaves drop' on messages exchanged with quantum cryptography. However, early implementations have been shown to have some weaknesses

Source: Expert interviews

Public and private funding is skyrocketing around the world, with North America currently investing the most

The QT market is still dominated by North America

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

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

China leads in commercial implementation of QComms. Japan is the front-runner in QT industry adoption

Funding is rising rapidly

Announced raised funding for 2021 (~$2.1 bn) is already almost triple the total funding of nearly $800 m raised in 2020

Announced major deals for 2021 extend to software and QComms players

China has committed $15 bn over 5 years for QT; the European Union announced $7.2 bn

Global market participation is increasing

The United Kingdom is catching up to North America due to recent major deals

China leads in patents and is expected to catch up rapidly on QC

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

There's momentum in all areas of QT; QC 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)

213[1]

$3.3 bn[2]

$9 bn–$93 bn[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]

$0.3 bn[2]

$1 bn–$7 bn[3]

Quantum communications (QComms)

111[1]

$0.6 bn[2]

$1 bn–$6 bn[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 for 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

Market activity and QT breakthroughs are accelerating

Not exhaustive

QC — Quantum communications — Quantum sensing — Quantum overall

2000 — **2015** — **Today**

1999

EU invests €50 mn-€75 mn in QTs via Future and Emerging Technologies (FET) program over next 7 years (EU Flagship program)

1999

The first commercial special-purpose QC company is founded

2001

First announcement of commercial R&D project on QComms

2003

DARPA launches the 1st quantum network; it becomes fully operational in October 2003

2007

The first commercial offer of quantum key distribution services is launched

2007

The local government of Geneva protects voting systems with quantum key distribution for a federal election

2011

The first sale of a special-purpose quantum computer is announced at the price of $10m

2012

The first QC software company is founded

2014

Total yearly investments in QTs exceed $100 m for the first time; more than 10 QT companies are founded

2016

Large technology company offers open and premium access to their quantum computer

2016

First testing of quantum key distribution on commercial fiber lines

2016

Canadian government commits CA $76 m to the University of Waterloo for quantum hardware and software

2017

First industry announcement for QC partnership, in the automotive industry

Total yearly investments in QTs exceed $300 m; more than 30 new QT companies are founded

2018

First commercial Quantum 2.0 sensor, a gravity sensor, is launched

2018

First industry announcement for QC partnership in the chemicals industry.

Large technology companies start to incubate and consolidate the start-up ecosystems

2018

The European Commission announces a €1 bn project to support quantum researchers over the next 10 years (Future and Emerging Technologies Flagship)

2019

Launch of first online QC platform via the cloud by large technology company

2019

Launch of first quantum cloud service offering access to hardware of multiple providers through one platform

2019

American company makes the first claims to "quantum supremacy"[1]

2020

Chinese researchers demonstrate quantum supremacy on photonic hardware

2020

First major (>$300 mn) investment is made into quantum communication, for the launch of quantum encryption satellites in 2023

2021

Sequence of announcements of 3 major investments, ranging from $300-650 m in QC start-ups

2021

World's most powerful quantum computer (volume 512) is announced

1. Quantum supremacy: an event defined by the resolution of a quantum computation that cannot be done by the most powerful classical computers in a practical amount of time.

Source: Expert interviews, press search June 2021 McKinsey analysis

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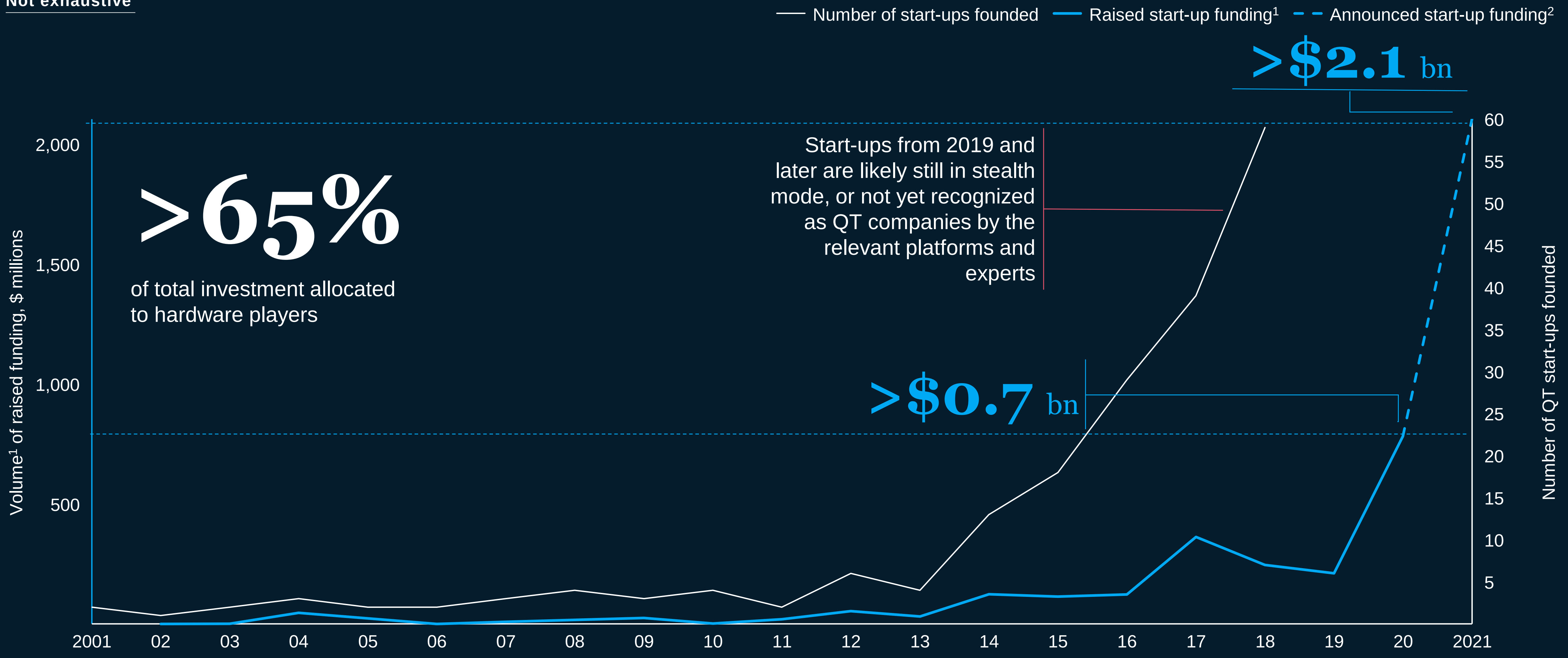
QT founding and investment activity reached >$700 m in 2020 and are expected to grow further this year

Not exhaustive

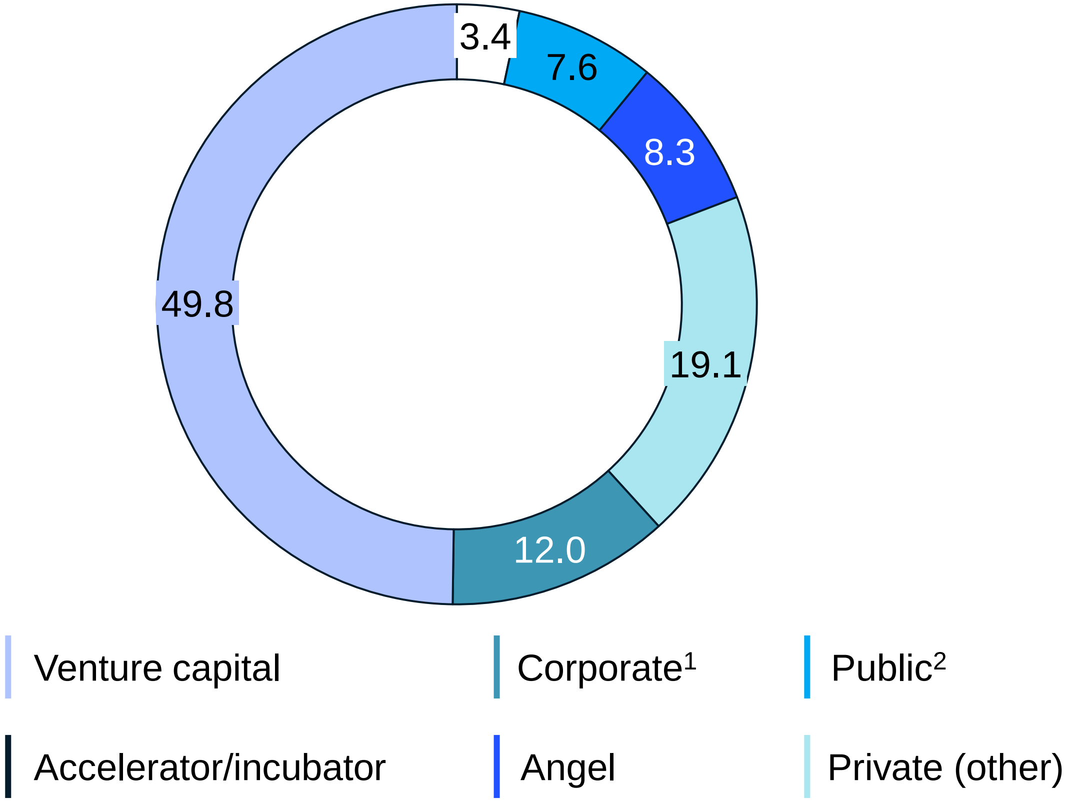


1. Based on public investment data recorded in Pitchbook; actual investment is likely higher
2. Public announcements of major deals; actual investment is likely higher

Source: Pitchbook; McKinsey analysis

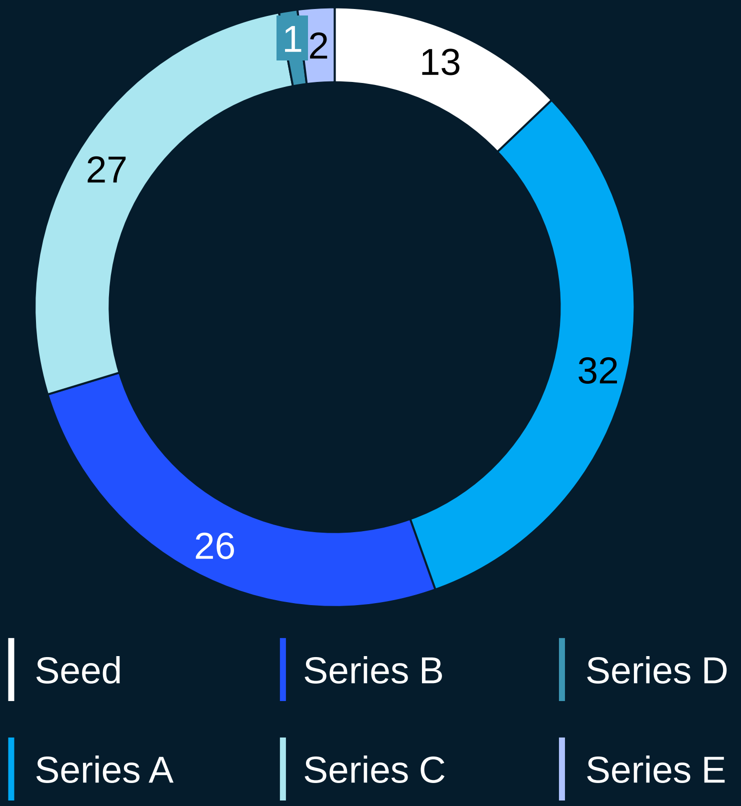
Venture capital accounts for more than half of QT investments, primarily funding start-ups and scale-ups

Split of investments 2001-21, by investor type
(percent of total 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

Split of VC investments, by deal type, 2001-21
(percent of total investment value)



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

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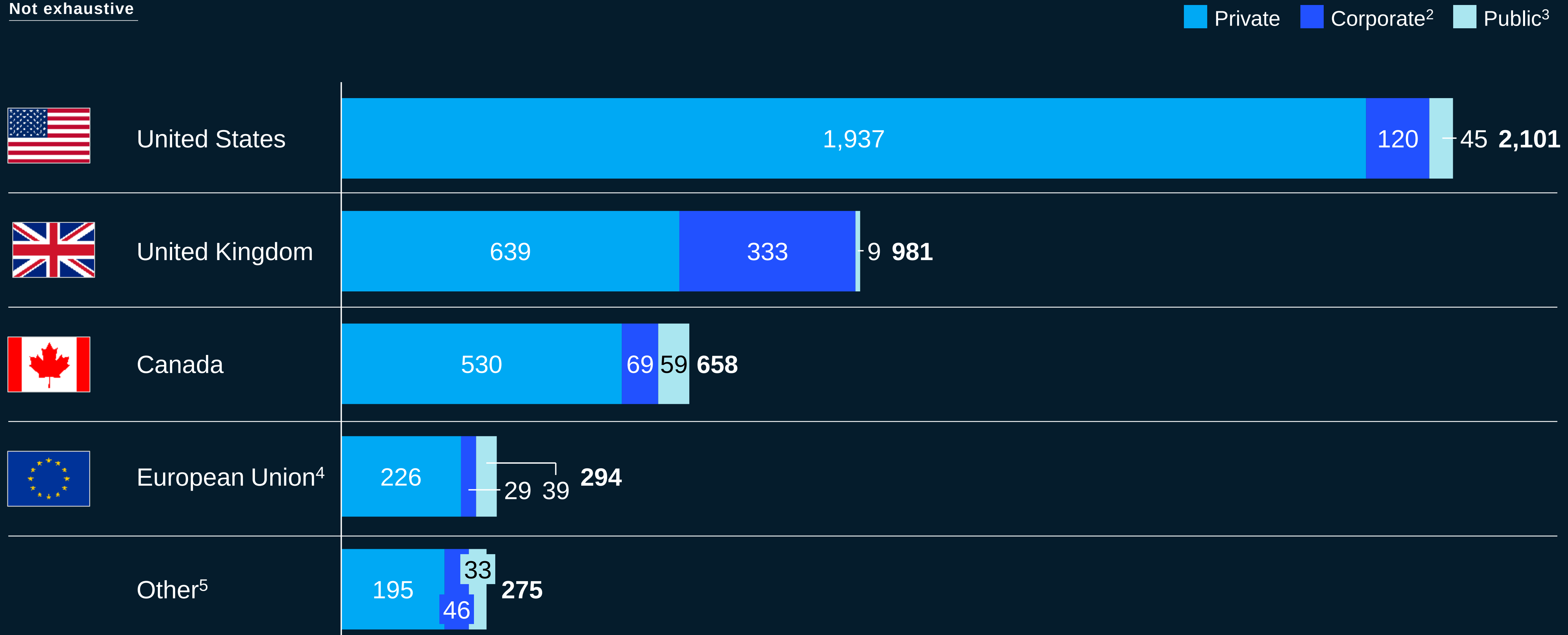
Majority of investments are in US companies, followed by the United Kingdom and Canada, driven primarily by private investors

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

Not exhaustive



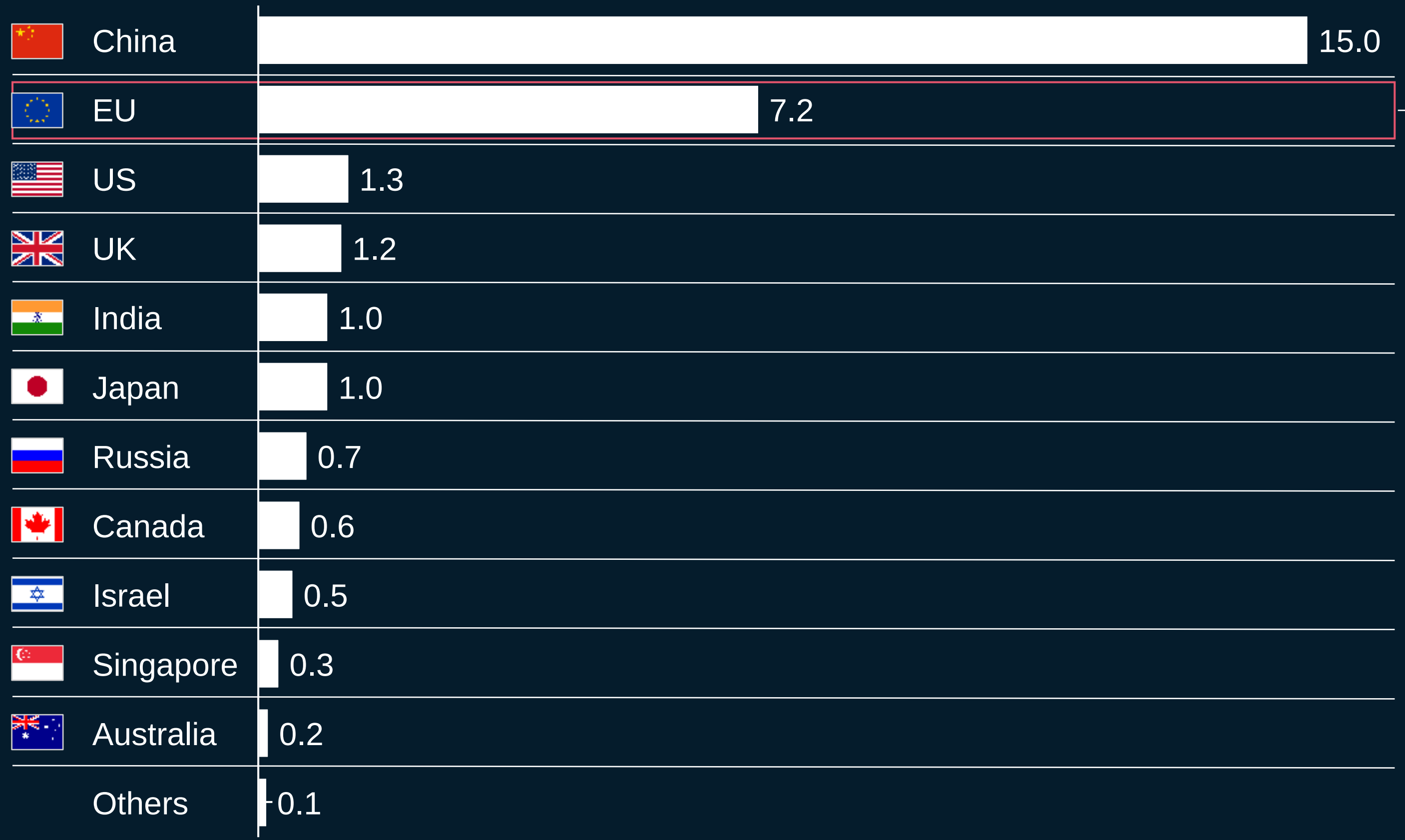
1. Based on Pitchbook data; includes announced deals for IonQ, Arqit, Cambridge Quantum Computing, and PsiQuantum. Actual investment volume in QTs is likely higher.
2. Includes investments from corporations and corporate venture capital in external start-ups. Excludes corporate investments in internal QT programs.
3. Includes investments by governments, sovereign wealth funds and universities.
4. Includes European Union, Switzerland and Norway.
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.

Source: PitchBook; McKinsey analysis

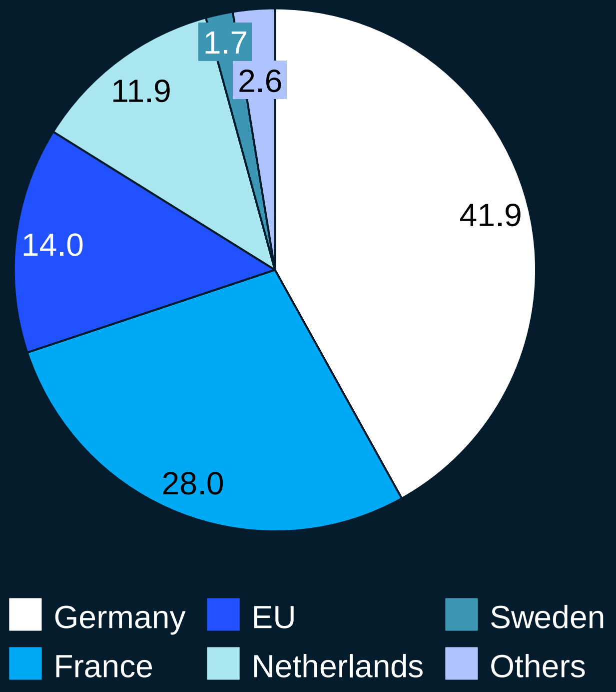
China and the European Union lead in announced public funding

Not exhaustive

Announced planned governmental funding[1]
$ billions



EU public funding sources, percent



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

Source: CIFAR report: A quantum revolution: Report on global policies for QT; press search June 2021

The United States and Canada are most active in QC

Number of QCplayers, by country

Not exhaustive

Geographic details on next slide

Number of QC players, by country		**Start-ups**	**Incumbent companies**	**Public/ government organizations**	**Academic groups**
Top 7	United States	59	9	18	63
	Canada	23	0	2	9
	United Kingdom	19	1	2	13
	Japan	12	1	0	7
	France	8	1	3	9
	Germany	7	2	1	7
	[1] China	7	2	12	11
… and elsewhere[1]		61	1	19	50
Σ		**196**	**17**	**57**	**169**

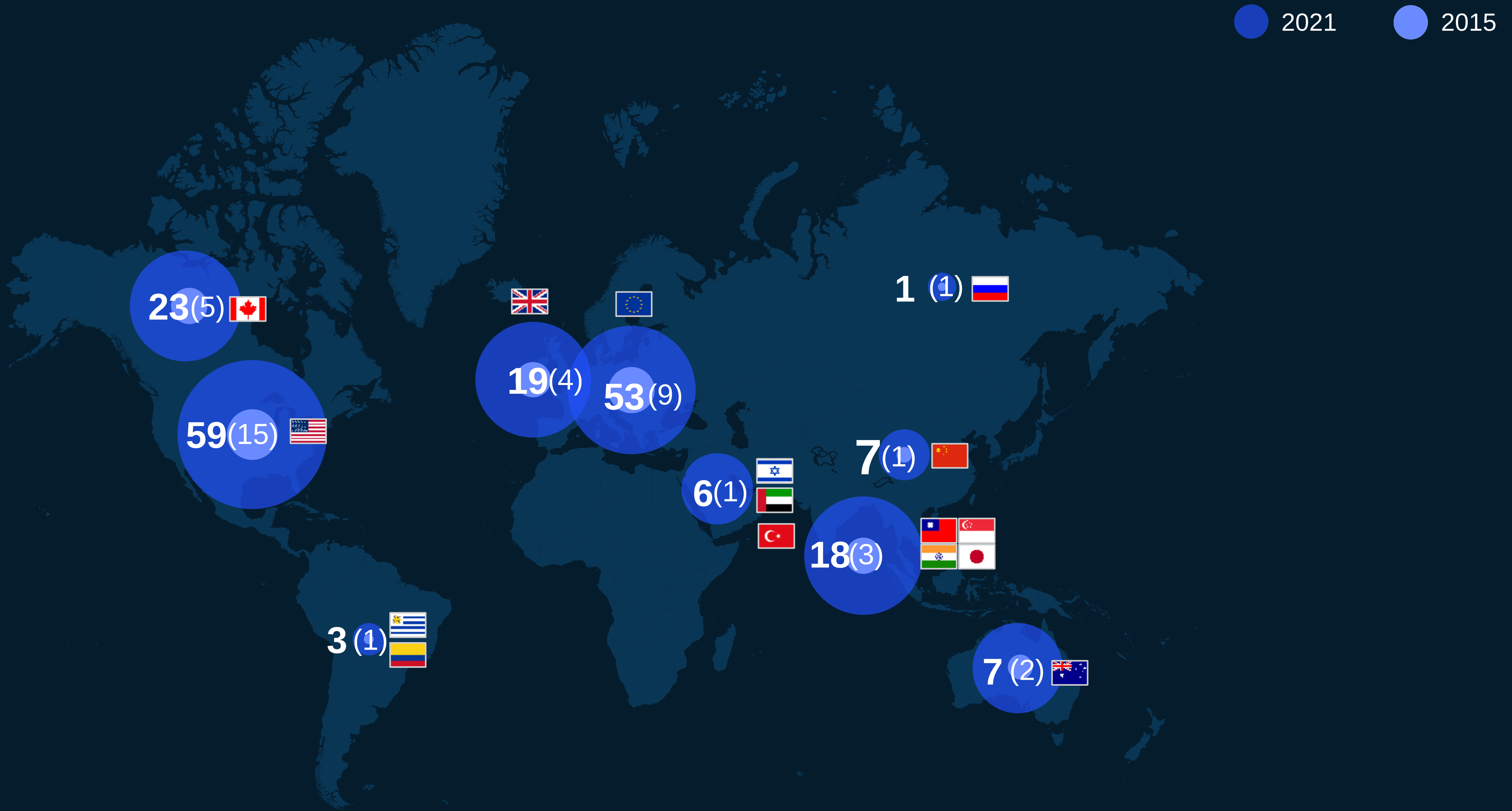
1. There is limited transparency on commercial activity in China and to a lesser extent for Japan. We think Chinese activity in QTs is primarily through government-funded research institutions

Source: Press and web research; McKinsey analysis

QC start-ups continue to emerge across the globe, led by the United States and the European Union

Number of QC start-ups, by region (today, and 2015 in brackets)[1]

Not exhaustive

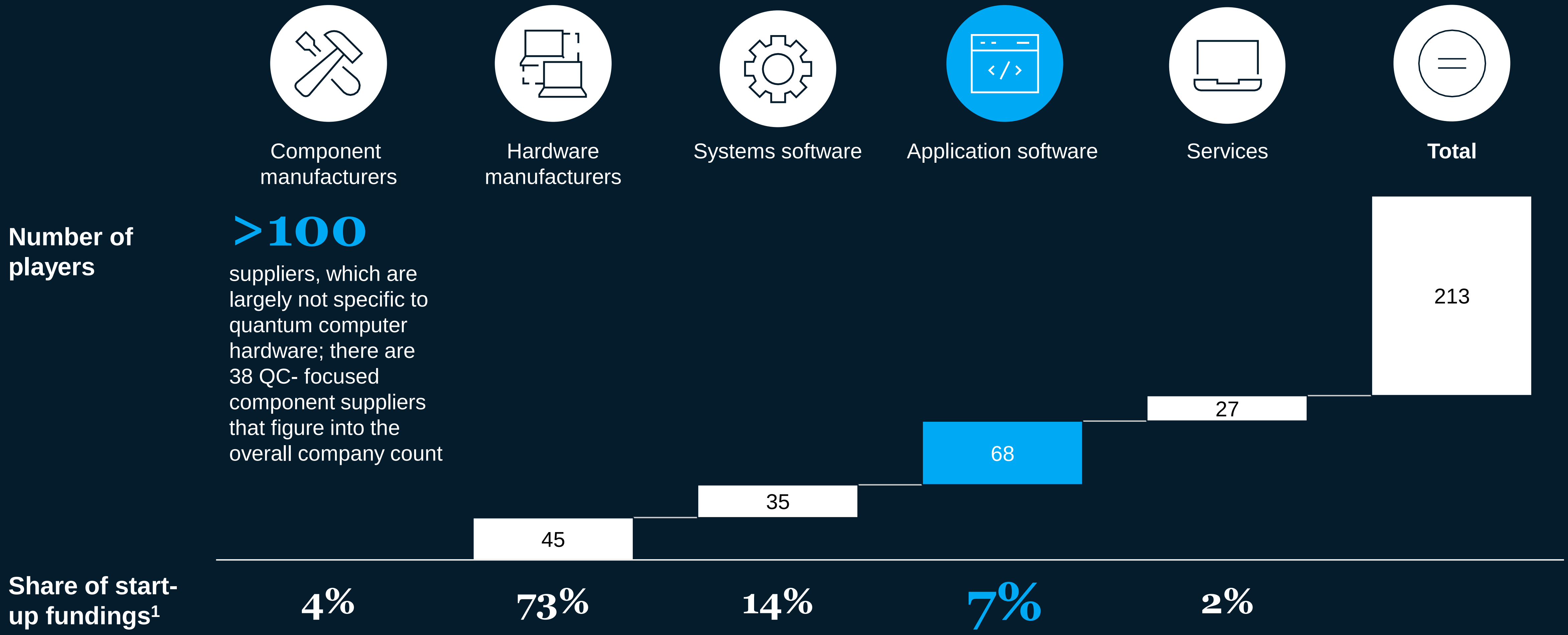


1. There is limited transparency on commercial activity in China and to a lesser extent for Japan. We think Chinese activity in QTs is primarily through government-funded research institutions.

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

Most players are in component manufacturing, followed by application software

Number of QC players by value chain segment[1]



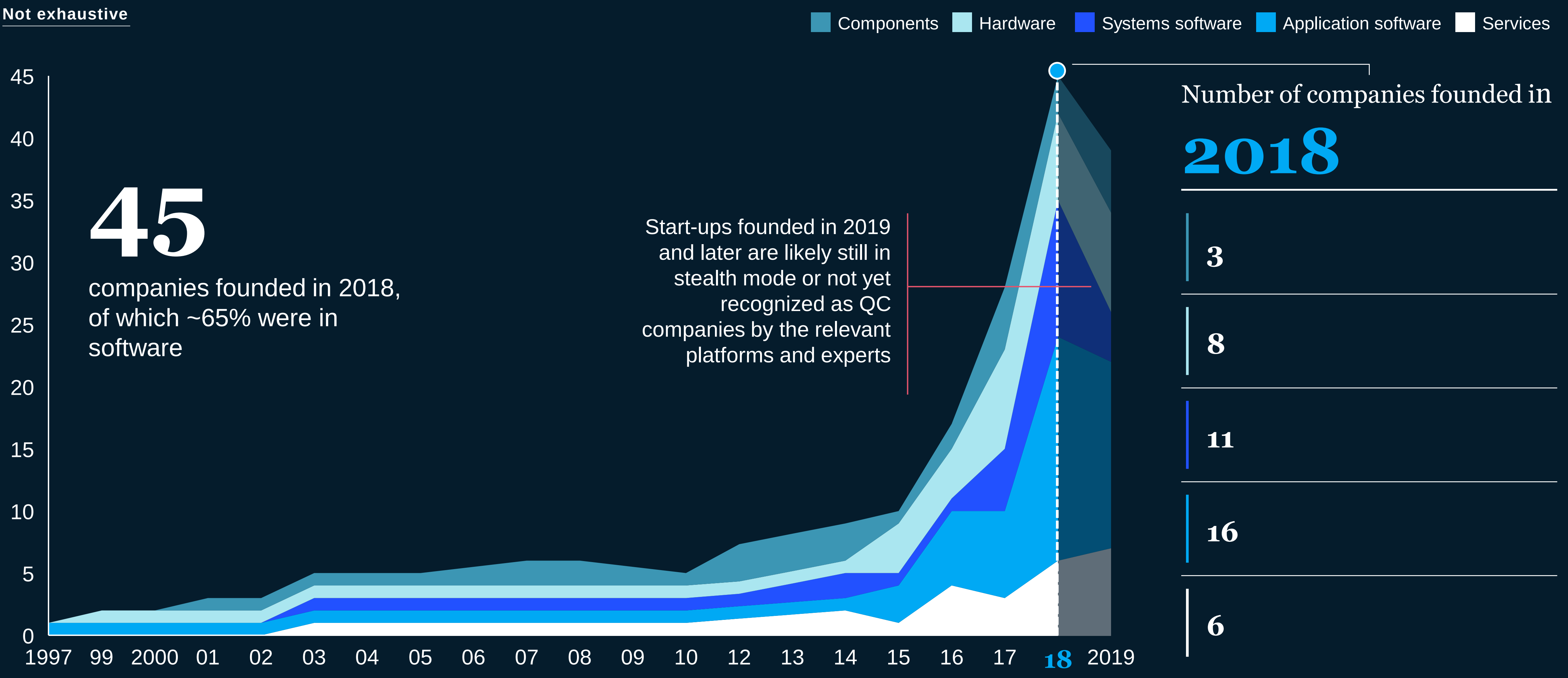
1. Includes start-ups and incumbents that develop or offer QT products; see methodology page for details
2. Based on public investments in start-ups recorded on Pitchbook and announced in the press; includes announced deals for 2021; excludes investments in internal QT departments or projects by incumbents;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

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

Whereas the largest single investment deals are in hardware, application software is the fastest-growing segment

Number of QC start-ups founded per year (excluding China)[1]

Not exhaustive



1. Number only quoted until 2018, since start-ups with a later founding date may still be in stealth mode, i. e. they have not disclosed their activity publicly. Next publication will likely contain start-ups up to 2019

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

The QC ecosystem is dominated by large technology players

The **core parts** of the QC ecosystem **(hardware and software)** 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 component segment is 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 few key industries	The service segment is split between consulting services and cloud services.

1. Funding/revenue ranges defining maturity : > $100 m – high, $1m-$100 m – medium, $10.000-$1 m – low, < $10.000 – very low/unknown.

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

Not exhaustive

The component segment is the most mature; yet there is room for specialized players

The component segment is generating revenue

The component 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 few scale-ups, with most capital in superconducting qubits

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

Not exhaustive

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

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

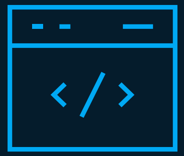
Most products are in prototype phase

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



Despite a large number of players, application software is immature

The application software market has emerged in the last 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 service segment is split between consulting services and cloud services

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

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Several industries are already working in "stealth mode" on competitive applications of QC

Adoption of QC technology, by industry vertical

Bystanders

No explorative activities in the realm of QC have been publicly announced by industries players so far

- Healthcare systems and services
- Public and social sector, professional services

Beginners

Industry players have formed the 1st partnerships and/or consortia to explore initial QC use cases (precompetitive)

- Consumer goods
- Insurance
- Travel, transport, and logistics
- Advanced industries
- Global energy and materials

Amateurs

Several precompetitive activities have moved to a competitive stage and industry players have started to hire quantum scientists

- Automotive and assembly
- Chemicals
- Pharmaceuticals and medical products
- Aerospace and defense
- Finance

Professionals

Industry players have started to realize business impact via proprietary QC applications and adhere to a strategy

- Telecommunications, media, and technology[1]

Legends

Innovation related to the applications of QC plateaued, but use cases continue to create value

2.9/5

The adoption rate of QC, based on industry survey with ~300 participants

Adoption of technology

1. Technology companies are QC hardware manufacturers and software developers.

Source: McKinsey analysis

Near-term impact of QC expected to be in chemicals, pharmaceuticals, automotive, banking, and defense

Illustrative

Horizons Primary value pools **Economic value** Incremental Significant Disruptive

Economic value ($ trillions)

Industry	Key segment for QC	Impact of QC[1] ~2025-30	Impact of QC[1] ~2030-35	Industry size
Global energy and Materials	Oil & gas	Incremental	Significant	5-10
	Sustainable energy	Significant	Disruptive	1-5
	Chemicals	Significant	Disruptive	1-5
Pharmaceuticals and medical products	Pharmaceuticals	Significant	Disruptive	1-5
Advanced industries	Automotive and assembly	Incremental	Significant	1-5
	Aerospace and defense	Incremental	Significant	<1
	Advanced electronics	Incremental	Significant	<1
	Semiconductors	Incremental	Significant	<1
Financial industry[1]		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 for QC; McKinsey analysis

Outlook

Impact from QC is expected to be most disruptive for the chemicals and pharmaceutical industries, as quantum-computing-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 value at stake is high, especially in asset management

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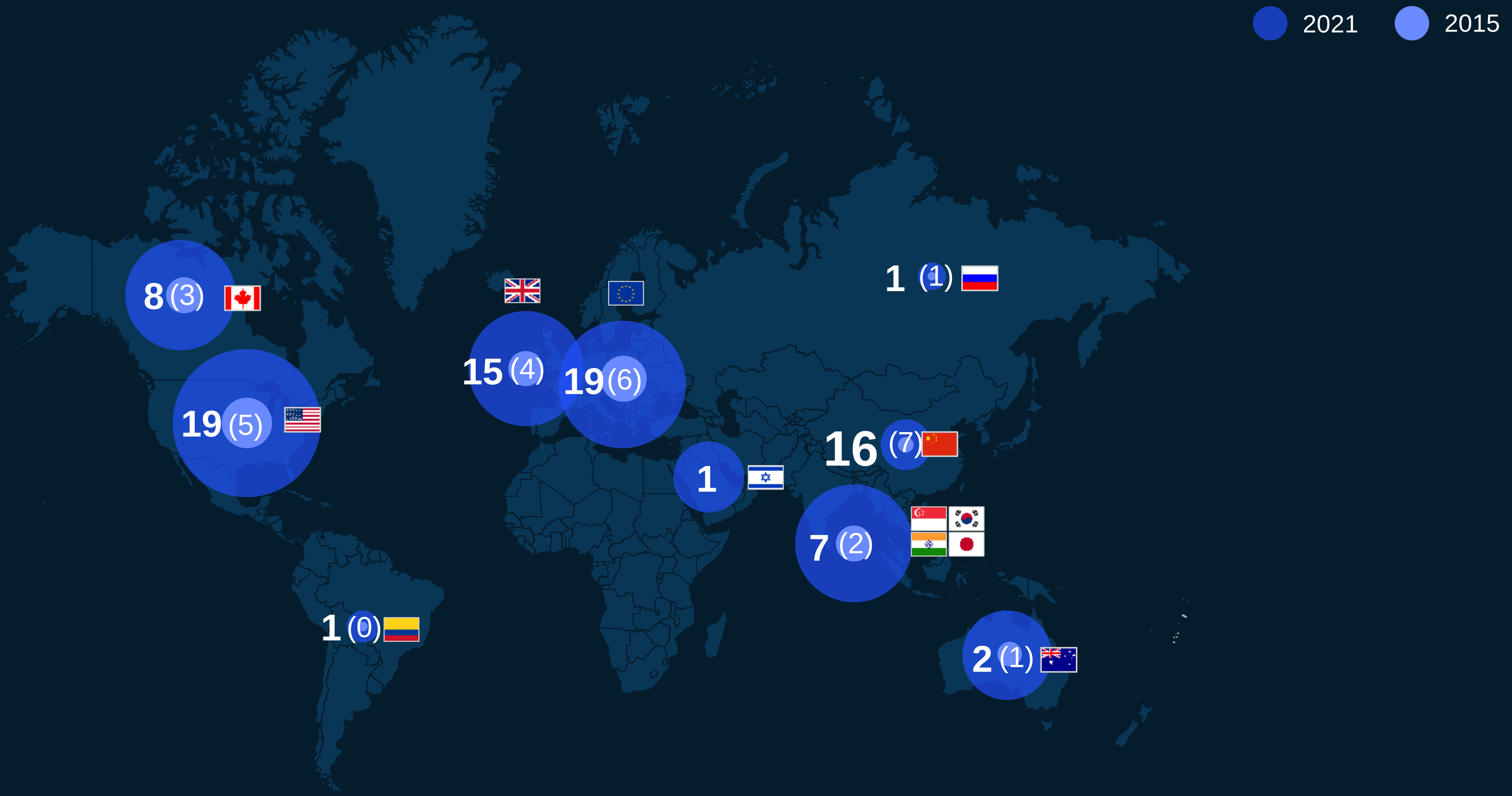
QComms start-ups continue to rise across the globe, led by the United States and the European Union

Number of QComms start-ups (excluding China), by region (today, and 2015 in brackets)

Not exhaustive

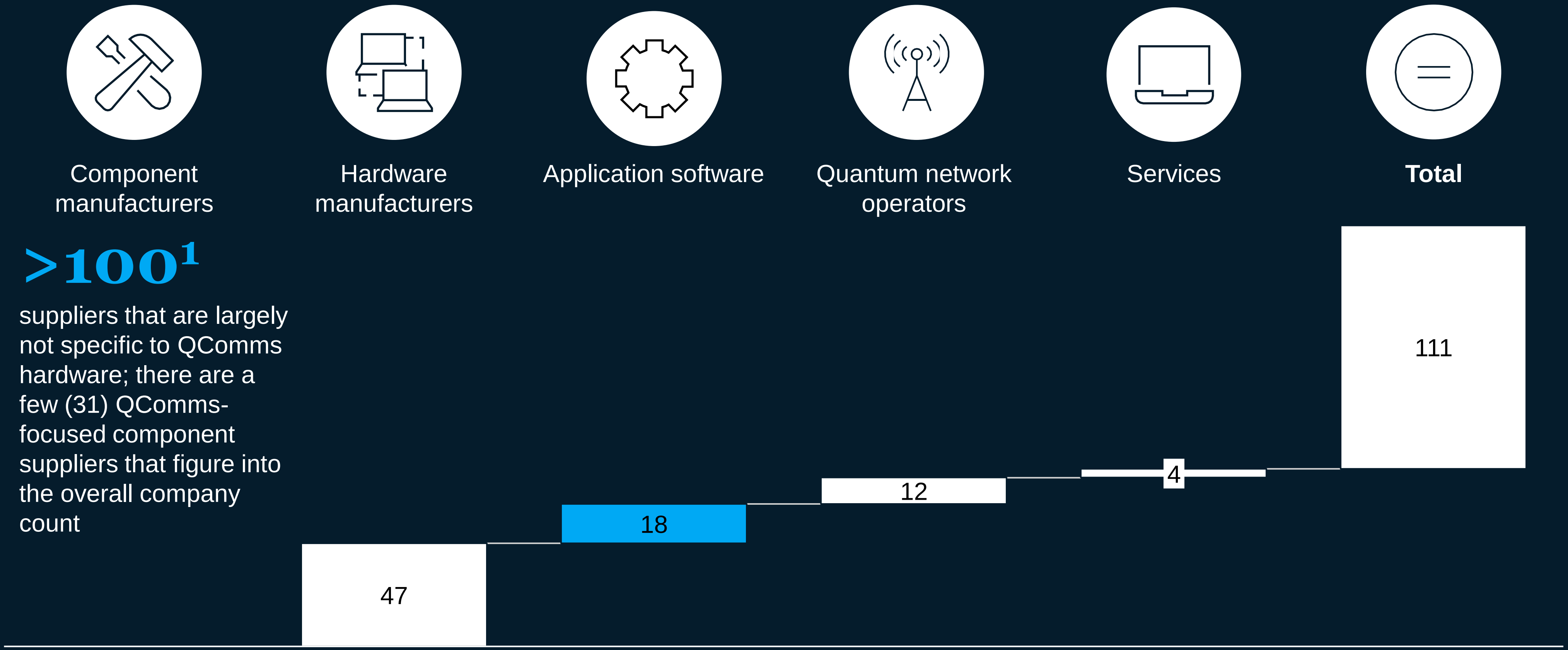


Source: CapitalIQ; Crunchbase; Pitchbook; press search; Quantum Computing Report; Expert interviews; McKinsey analysis

Most funding is raised in applications, despite the relatively small number of players

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 page 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 ($400 m) for Arqit (United Kingdom) to develop quantum satellite communication

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

The **core parts** of the QC ecosystem **(hardware and software)** 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	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.

1. Funding/revenue ranges defining maturity : > $100 m – high, $1m-$100 m – medium, $10.000-$1 m – low, < $10.000 – very low/unknown.

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

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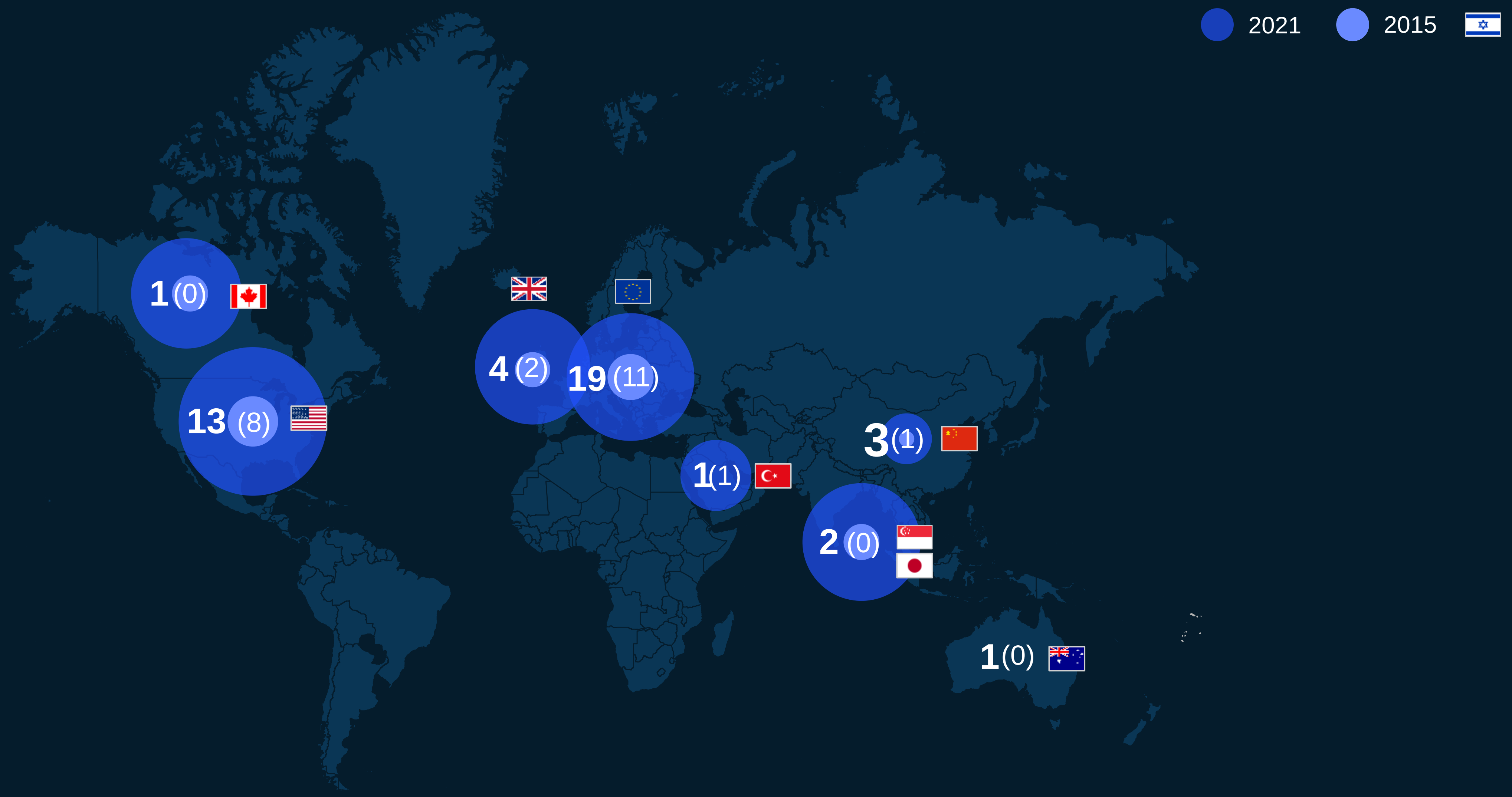
The amount of players in QS has nearly doubled over the last 5 years; however, numbers are still modest

Number of QS start-ups (excluding China), by region (today, and 2015 in brackets)

Not exhaustive



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

Overall investment in QS is still low, with majority of players and funding in 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) quantum-sensing-focused component 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 page 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 at the prototype stage

Non-exhaustive

The **core parts** of the QC ecosystem **(hardware and software)** 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**	**Application software**
The component segment of the QS market is most mature; manufacturers sell commercial products, but push-button solutions do not yet exist	Hardware products are mostly at the level of prototypes. They require optimization in price, size, and weight to become competitive beyond niche markets	The application and service segment has few players; it is expected to grow as hardware matures

1. Funding/revenue ranges defining maturity : > $100 m – high, $1m-$100 m – medium, $10.000-$1 m – low, < $10.000 – very low/unknown.

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

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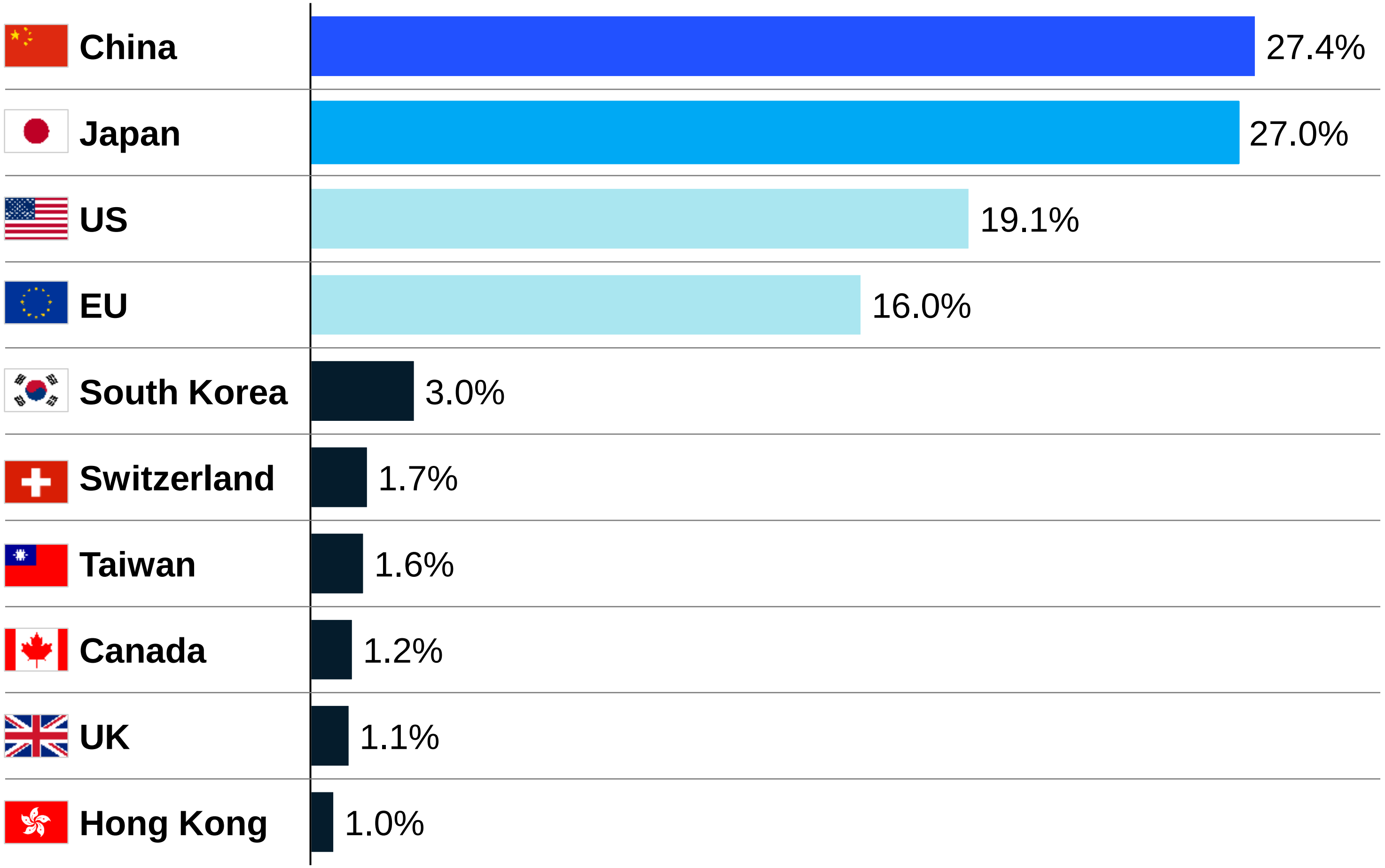
China is leading in QT patent activity

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

Preliminary



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

Source: Expert interviews; Innography; McKinsey analysis

Key takeaways

China has increased its share of patents in recent years, indicating increased activity in QT; leading organizations are the Chinese Academy of Sciences, Huawei, and Tsingua University

Japan has been among the top 3 in 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 were leading on patents until ~2005, when a number of filings started declining due to change in culture around IP; the United States still lead on hardware patents, mainly driven by IBM and Google

The European Union leads in quantum-relevant publications, but the United States outcompetes in impact

As of 2020

XX Rank of country's h-index

Top 10 countries worldwide 2020, by h-index

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

Rank	Country	Share of articles
1	US	11%
2	UK	4%
3	EU	23%
4	China	21%
5	Canada	2%
6	Japan	3%
7	Switzerland	1%
8	Australia	2%
9	Israel	1%
10	South Korea	2%

Top 5 EU countries

Share of articles and H index, 2020

Rank	Country	Share of articles
1	Germany	4%
2	France	3%
3	Italy	3%
4	Spain	2%
5	Netherlands	1%

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

Source: SCImago Journal & Country Rank; McKinsey analysis

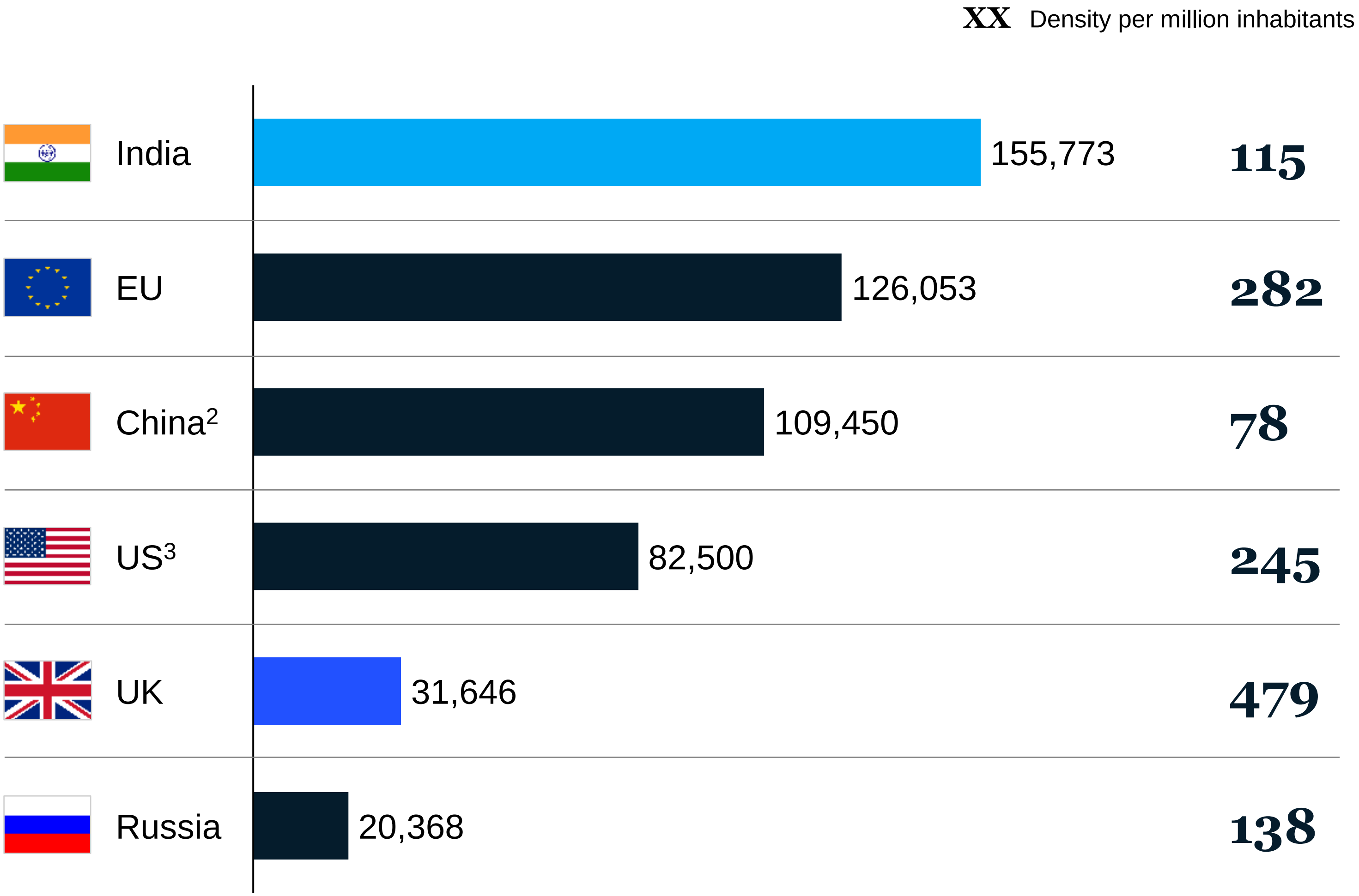
Key takeaways

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

The EU is leading in terms of **published articles** in 2020 in quantum-relevant fields, followed by China and the US

India leads with the most quantum-relevant talent

Absolute number of graduates,[1] 2018



1. Enrolled students at master's level or equivalent in 2018 in physical sciences, mathematics, and statistics, and information and communications technology
2. High-level estimates
3. The actual talent pool for the United States may be larger, as bachelor programs are longer and master programs are less common

Source: National government websites; OECD; McKinsey analysis

Key takeaways

India is leading in terms of number of **quantum-relevant graduates,** followed by the European Union and China

The UK has the highest concentration of **quantum-relevant talent,** followed by the European Union and the United States

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
  - — PsiQuantum announced that it will manufacture a commercially viable quantum computer with ~106 qubits by 2026
- While the United States and Canada have been market leaders for the last decade, China and the EU 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 service players
- Several large investment rounds have already been announced for 2021 (eg IonQ, ~$650 m, ArQit, ~$345 m, Cambridge Quantum Computing, ~$300 m, Xanadu, ~$100 m), suggesting that the investment activity around QC will continue to grow
- Chinese researchers have 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 the ~$10 bn government fund for QC

Stimulated by government funding, China is making strides in QT

In December 2020, researchers from the Hefei National Laboratory claimed quantum supremacy with a photonic prototype

~$15 bn

for QTs as part of China’s 14th 5-year plan (2016–20)

~$1 bn

In funding for a governmental laboratory completed in 2020

~27%

Patents related to QT were filed by companies with headquarters in China in 2018 (1.5x as many as in the United States)

12

Dedicated QT research institutions

32

companies are active in QT

Technology giants

Large Chinese companies have started developing quantum products

Source: Press and web search; McKinsey analysis

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Methodology (1/4)

QT temperature and industry positioning

- The QC temperature is based on a survey across >300 industry leaders globally and their opinion on the impact of QC on their respective industry. The impact assessment across industries is based on a use case exploration with >50 industry leaders, data scientists, and QC experts

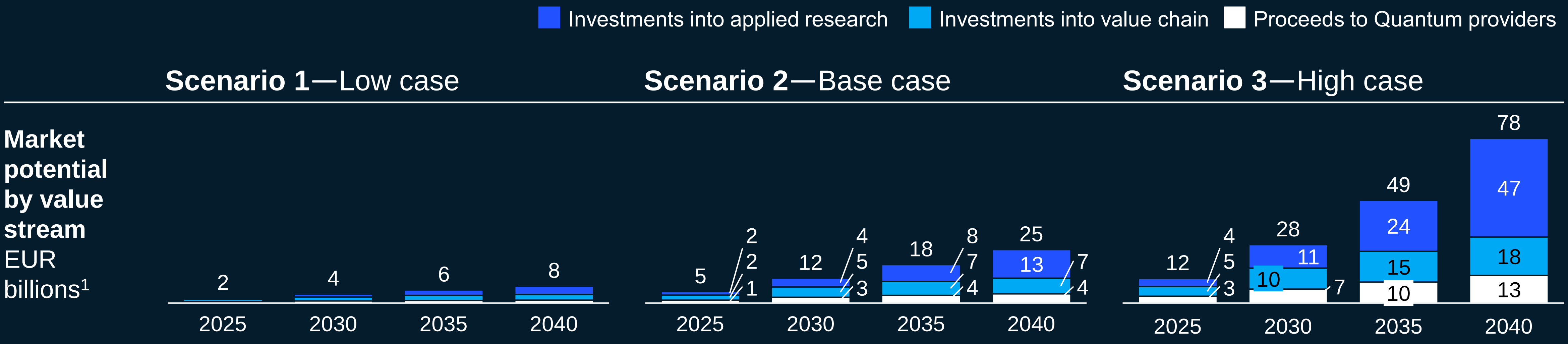
Quantum technology player landscape and investment

- To obtain the Quantum Computing player landscape, we considered the following entities
  - Start-ups: founded in the last 25 years with estimated revenues below $200 m
  - Incumbent companies: companies with revenues above $200 m
- Component manufacturers are considered as such if they develop components specifically for QC; 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
- Telecommunication companies are considered as such if they invest in QComms to become a quantum network operator
- Relevant general technology component 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]

1. Total funding for start-ups focusing on multiple technologies is split evenly across technologies

Methodology (2/4)

Potential value captured by QC players[1]



What you need to believe

Scenario 1—Low case

QC hardware and application development face more challenges than currently expected. QC hardware remains limited to special-purpose QC, or quantum solutions do not live up to their promise in real-life applications

QC provides substitute for HPC, only in niche areas (eg, optimization or molecular simulation)

HPC market growth will slow down as cloud-based parallel computing will gain share

Scenario 2—Base case

QC hardware and application development progresses steadily and reaches maturity by 2040

QC provides substitute for HPC in a broad range of areas, including AI/ML

Business value impact is incremental; QC spend substitutes HPC spend to limited extent, upside potential driven by QC opening new possibilities

Scenario 3—High case

QC hardware and application development progresses rapidly, reaching fault-tolerance before 2030

QC usage costs decreases greatly while performance increases strongly

QC achieves high business value across industries, leading to broad adoption

QC opens new possibilities to solve problems (ie, that HPC was not used for), inducing additional market growth and high market share

1. Does not included value generated by QC in different industries.

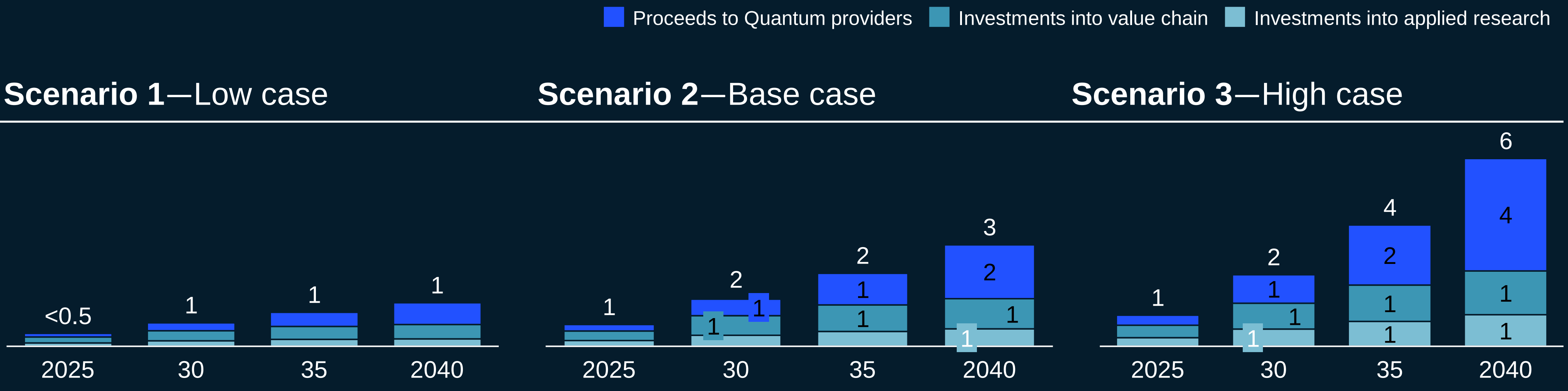
Source: McKinsey analysis

Methodology (3/4)

QComms market potential

Scenario 1—Low case | **Scenario 2**—Base case | **Scenario 3**—High case

Market potential by value stream
EUR billions[1]



What you need to believe

Scenario 1—Low case

Classical post-quantum cryptography (CPQC) able to protect all communication sufficiently at lower cost than quantum encryption

Only a few players require long-term security of quantum encryption and implement it in small parts of their systems.

Scenario 2—Base case

CPQC proves valuable for most users, but risk of cracking remains possible theoretically

Many large corporates use quantum cryptography, but only for their most critical connections between central points in their network

Scenario 3—High case

CPQC faces many roadblocks for implementation

Race to crack CPQC intensifies due to fast progress developing quantum computers

Most corporates / institutions use quantum encryption in most servers' connections

Overall assump- tions

Network security (eg, due to quantum encryption) assumed as most likely commercial use case in next 20 years

QComms captures share of spend on network cybersecurity hardware as quantum encryption likely is the main use case

Quantum internet may become relevant towards 2035/2040 (ie, not included in estimations)

1. Totals might differ due to rounding effects

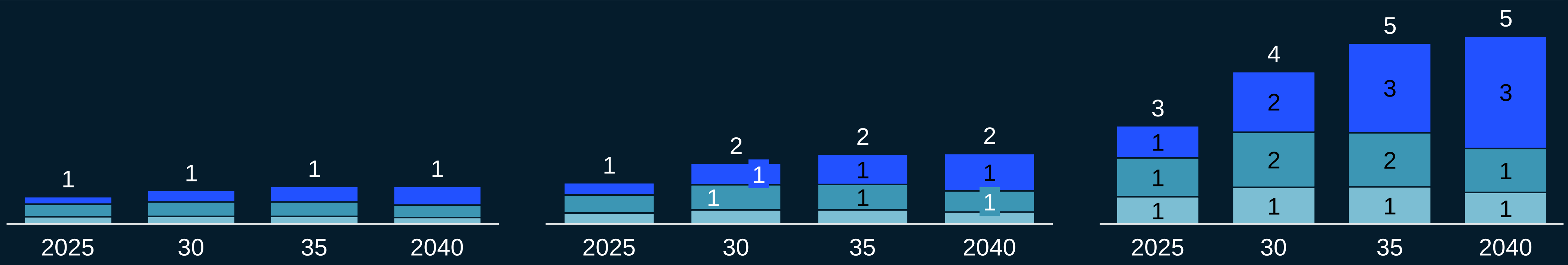
Source: McKinsey analysis

Methodology (4/4)

QSmarket potential

Proceeds to Quantum providers | Investments into value chain | Investments into applied research

	Scenario 1—Low case	Scenario 2—Base case	Scenario 3—High case
Market potential by value stream EUR billions[1]			



	Scenario 1—Low case	Scenario 2—Base case	Scenario 3—High case
What you need to believe	Quantum sensors remain costly with a large footprint Only ~2 use cases scale well with most applications focused on scientific use	Some quantum sensors become smaller and increasingly implemented in further products Commercial applications requiring ultra high precision is limited, approx. one scaling use case per main category of sensing (see below)	Quantum sensors successfully reduce their footprint and costs Many new applications for ultra high fidelity sensors arise, and sensors are used in many products, with ~3 use cases per main category of sensing

Overall assump-tions

Market potential determined by sizing possible use cases into 4 categories: NV sensors, optical atomic clocks, gravity sensors, and photonic entanglement sensors – excluding “Quantum 1.0” sensors like MW atomic clocks/SQUIDs

VC / corporate investment partially shifts to QC/QComms once they significantly outgrow sensing

1. Totals might differ due to rounding effects

Source: McKinsey analysis

McKinsey & Company