What is the Quantum Computing Monitor?

- Dynamic overview of industries’ **maturity toward quantum computing**, based on the current application of the technology
- Continuously evolving overview of the **global quantum computing player & investment space**, updated 6-monthly

... and what it is not:

- **Definitive & exhaustive list** of the start-up and funding activities in the quantum computing realm as it evolves too rapidly
Key Facts

60% of start-ups and incumbent companies in the G7 are located in North America

G7 members account for more than 70% of quantum computing startups worldwide

Investments in the past 5 years show a compound annual growth rate of 80% with 0.5 billion USD in 2020 alone representing about one third of all investments so far

About 90% of investment is focused on hardware manufacturers

~60% of quantum computing players are active in the systems and algorithm layers

Quantum computing hardware manufacturers are 35-40 globally

1. Excluding China, due to a lack of data
Quantum technologies are accelerating

**Not Exhaustive**

### 2000

- **1999**
  - EU invests €50-75 million in quantum technologies via Future and Emerging Technologies (FET) program over next 7 years (EU Flagship program)
- **2001**
  - SK Telecom starts R&D on quantum communication
- **2003**
  - DARPA launches the first quantum network; it becomes fully operational in October
- **2007**
  - ID Quantique starts commercially offering quantum key distribution services
  - The local government of Geneva protects voting systems with quantum key distribution for a federal election

### 2015

- **2015**
  - Intel invests $50 M in QuTech Delft to develop a quantum computer
- **2016**
  - IBM starts making their quantum computers available to the public for the first time with the IBM Q program
  - IBM and Google start to incubate and consolidate the startup ecosystems
- **2017**
  - Volkswagen announcing co-development with Google
  - Several dozens of startup are founded
- **2018**
  - MuQuans develops first commercial Quantum 2.0 sensor, a gravity sensor
  - DowDuPont announce co-development with 1QBit to develop quantum tools in the areas of chemicals and material science
  - IBM and Google start to incubate and consolidate the start up ecosystems

### Today

- **2019**
  - IBM launches online platform IBM Q Experience via the cloud
  - Google announces Quantum cloud service “Azure Quantum” in cooperation with Honeywell, IonQ and QCI
  - Honeywell announces world’s most powerful quantum computer (volume 128)
- **2020**
  - Microsoft announces Quantum cloud service “Azure Quantum” in cooperation with Honeywell, IonQ and QCI

**Source:** McKinsey analysis, expert interviews, press search
## Public funding for quantum computing

<table>
<thead>
<tr>
<th>Country</th>
<th>Funding (bn USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>2.5 p.a.</td>
</tr>
<tr>
<td>Germany</td>
<td>2.7</td>
</tr>
<tr>
<td>USA</td>
<td>2.2</td>
</tr>
<tr>
<td>India</td>
<td>1.2</td>
</tr>
<tr>
<td>EU</td>
<td>1.2</td>
</tr>
<tr>
<td>Japan</td>
<td>0.9</td>
</tr>
<tr>
<td>Russia</td>
<td>0.8</td>
</tr>
<tr>
<td>UK</td>
<td>0.8</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.5</td>
</tr>
<tr>
<td>Australia</td>
<td>0.1</td>
</tr>
<tr>
<td>Singapore</td>
<td>Less than 0.1</td>
</tr>
</tbody>
</table>

*Source: CSIRO, McKinsey analysis*
Several industries are already working in “stealth mode” on competitive applications of quantum computing

Adoption of quantum computing technology, by industry vertical

**Bystanders**
- No explorative activities in the realm of quantum computing have publicly been announced by the industry’s players so far

**Beginners**
- Industry players formed first partnerships and/or consortia to explore first quantum computing use cases (pre-competitive)

**Amateurs**
- Several pre-competitive activities have moved to a competitive stage and industry players start to hire quantum scientists

**Professionals**
- Industry players start to realize business impact via proprietary quantum computing applications and adhere to a strategy

**Legends**
- Innovation related to the applications of quantum computing in an industry plateaued but use cases continue to create value

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1. Technology companies are quantum computing hardware manufacturers and software developers

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Source: McKinsey analysis

2.9/5

the adoption rate of quantum computing based on industry survey with ~300 participants
Experts expect the impact of quantum computing in the mid-term to be greatest in AI, GEM, Finance and TTL.

<table>
<thead>
<tr>
<th>Economic value</th>
<th>Economic impact share</th>
</tr>
</thead>
<tbody>
<tr>
<td>~2025</td>
<td>~2035</td>
</tr>
</tbody>
</table>

### Primary value pools (until ~2025)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Economic value</th>
<th>Economic impact share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Industries</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Consumer</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Global Energy &amp; Materials</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Telecom, Media &amp; Technology</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Finance</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Insurance</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Healthcare Systems &amp; Services</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Pharmaceuticals &amp; Medical Products</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Travel Transport &amp; Logistics</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Public and Social Sector, Professional Services</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>

### Secondary value pools (beyond ~2025)

- **Quantum simulation**: Low Medium High
- **Optimization**: Low Medium High
- **Quantum AI/ML**: Low Medium High
- **Prime factorization**: Low Medium High

*Source: McKinsey analysis*
**Most players are active in the systems, software & algorithms layer**

Number of quantum computing players, by value chain segment

<table>
<thead>
<tr>
<th>Components</th>
<th>Hardware for comm. purposes</th>
<th>Systems, software &amp; algorithms</th>
<th>Total number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppliers</td>
<td>&gt;100(^1)</td>
<td>85-105</td>
<td>135-160</td>
</tr>
<tr>
<td>Suppliers focused</td>
<td>50-55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Only 8 of these companies counted in the overall number of quantum computing players
2. Does not include end-users with their own quantum computing teams, e.g., the Volkswagen DataLab or Airbus

Source: McKinsey analysis, web research
### The US and Canada are most active around quantum computing

Number of quantum computing players (excl. China), by country and origin

<table>
<thead>
<tr>
<th>Number of QC players, by country</th>
<th>Start-ups</th>
<th>Incumbent companies</th>
<th>Public-/gov.-organizations</th>
<th>Academic groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top 7</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>36</td>
<td>13</td>
<td>14</td>
<td>38</td>
</tr>
<tr>
<td>Canada</td>
<td>20</td>
<td>0</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>UK</td>
<td>13</td>
<td>0</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Germany</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Japan</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>France</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Spain</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>... and elsewhere</strong></td>
<td><strong>31</strong></td>
<td><strong>3</strong>²</td>
<td><strong>19</strong></td>
<td><strong>24</strong></td>
</tr>
<tr>
<td><strong>Σ</strong></td>
<td><strong>127</strong></td>
<td><strong>18</strong></td>
<td><strong>43</strong></td>
<td><strong>89</strong></td>
</tr>
</tbody>
</table>

1. Excluding China, due to a lack of data
2. Includes Chinese companies Baidu and Alibaba

Source: McKinsey analysis, web research

NOT EXHAUSTIVE
We have seen a stark rise in quantum computing start-ups globally

Number of quantum computing start-ups (excl. China), by region (today, and 2015 in brackets)

- **20** (6) Canada
- **36** (12) USA
- **51** (9) Europe
- **11** (2) Japan
- **4** (1) Australia
- + **4** (1) elsewhere

High-quality data on the Chinese quantum computing landscape is not available; As far as we know, Chinese players are government-funded / -owned research groups.

1. Excluding China, due to a lack of data

Source: McKinsey analysis, Pitchbook, Crunchbase
### The top 10 investments have been directed at hardware players

Top 10 VC/PE investments in quantum computing start-ups, ordered by deal size (descending)

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Value chain pos.</th>
<th>Deal size, Million USD</th>
<th>Deal year</th>
<th>Lead investors</th>
</tr>
</thead>
<tbody>
<tr>
<td>PsiQuantum</td>
<td>USA</td>
<td>Hardware mfg.</td>
<td>230</td>
<td>2019</td>
<td>Playground Global</td>
</tr>
<tr>
<td>PsiQuantum</td>
<td>USA</td>
<td>Hardware mfg.</td>
<td>215</td>
<td>2020</td>
<td>Atomico</td>
</tr>
<tr>
<td>Xanadu</td>
<td>CANADA</td>
<td>Hardware mfg.</td>
<td>100</td>
<td>(2021)</td>
<td>-</td>
</tr>
<tr>
<td>Rigetti</td>
<td>USA</td>
<td>Hardware mfg.</td>
<td>79</td>
<td>2020</td>
<td>Bessemer Venture Partners</td>
</tr>
<tr>
<td>Silicon Quantum Computing</td>
<td>AUS</td>
<td>Hardware mfg.</td>
<td>66</td>
<td>2017</td>
<td>University of New South Wales Endowment</td>
</tr>
<tr>
<td>IonQ</td>
<td>USA</td>
<td>Hardware mfg.</td>
<td>55</td>
<td>2019</td>
<td>Samsung Catalyst Fund</td>
</tr>
<tr>
<td>D-Wave</td>
<td>CANADA</td>
<td>Hardware mfg.</td>
<td>52</td>
<td>2017</td>
<td>PSP Investments</td>
</tr>
<tr>
<td>D-Wave</td>
<td>CANADA</td>
<td>Hardware mfg.</td>
<td>50</td>
<td>2016</td>
<td>-</td>
</tr>
<tr>
<td>Psi-Quantum</td>
<td>USA</td>
<td>Hardware mfg.</td>
<td>50</td>
<td>2017</td>
<td>Playground Global</td>
</tr>
<tr>
<td>Rigetti</td>
<td>USA</td>
<td>Hardware mfg.</td>
<td>50</td>
<td>2017</td>
<td>Alumni Ventures</td>
</tr>
</tbody>
</table>

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.

Source: McKinsey analysis, Pitchbook, Crunchbase
Founding & investment activity has grown rapidly in the last 5 years
Number new foudings / investment volume, by year

Volume of PE/VC investment, Mn $

<10% of total investment allocated outside of hardware players

Source: McKinsey analysis, Pitchbook, Crunchbase

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

NOT EXHAUSTIVE
Most newly founded start-ups are software & algorithm developers

Founding activity in quantum computing (excl. China), by new founding volume per year

Source: McKinsey analysis, Pitchbook, Crunchbase

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
Development of QC in China is driven by start-ups and researchers linked to the government

1 Billion USD Funding for a governmental laboratory

National Quantum Information Sciences Laboratory

First provincial and ministerial level key laboratory in the field of quantum information in China
Focus on theoretical and experimental research on quantum communication and quantum computing
The project is invested in total 7 billion RMB, and is completed and delivered by September 30, 2020

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

3 Startups are active in commercial quantum computing

Origin Quantum Computing

Founded in 2017 by a research team of the quantum information lab at the Chinese Academy of Sciences
Offers QCPU, quantum controlling hardware, quantum software, quantum cloud. In Sep 2020, Origin began to operate China’s first superconducting quantum computer outside the lab

Qasky

Founded in 2016 to commercialize quantum cryptography research at the Academy of Sciences
Plan to offer products and services for integrated solutions for quantum information security systems

QuantumCTek

First Chinese provider of multi-protocol network security products and services based on quantum

517 Patents related to quantum computing filed in China in 2018 (twice as many as US)

Related activities

Large Chinese companies are interested in quantum products:

Baidu

Search engine provider Baidu engages in Quantum AI and the design of computing architecture

The Alibaba Group hosts a quantum computing cloud qbit an 11 qubit computing device backend

Source: Press clippings, web research
Where is quantum headed?

- The race for technological leadership will continue between photonic, trapped-ion, and superconducting qubit devices
  - IBM announced a ~10³ qubit superconducting chip by 2023, more than an order of magnitude larger than the current Hummingbird chip
  - Honeywell aims to gradually scale its ion trap 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 2025

- More players across industries will move from pre-competitive explorations of quantum computing into competitive research (partly in “stealth-mode”)

- Several large investment rounds have already been announced for 2021 (e.g. Xanadu, ~100 mn USD), suggesting that the investment activity around quantum computing will continue to rise despite the COVID-19 pandemic

- 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 USD government fund for quantum computing
What will the Quantum Computing Monitor include next

Quantum computing talent pools
• Where is talent emerging or lacking
• What are typical talent flows from academia to industry

Quantum computing figures of merit
• What are the standards on qubit count, gate depth, or quantum volume and how do they relate with each other
• How close are today’s quantum computers from demonstrating quantum advantage in solving real business problems?

…and provide further deep-dives on current content
The team behind the Monitor

Niko Mohr
Partner
Dusseldorf

Anika Pflanzer
Partner
Munich

Henning Soller
Partner
Frankfurt

Mathis Friesdorf
Associate Partner
Berlin

Matteo Biondi
Specialist
Zurich

Philipp Hühne
Digital Communication Specialist
Dusseldorf

Lorenzo Pautasso
Fellow Associate
Munich
Appendix
Classical computing

1 classical bit
- Bit can store zero or a one

2 classical bits

N classical bits

Quantum computing

One quantum bit
- Superposition state of two quantum states 0 and 1
- 2 (complex) coefficients are required to describe the superposition

2 quantum bits
- Superposition state of 4 quantum states 00, 01, 10, 11
- 4 (complex) coefficients are required to describe the superposition

N quantum bits
- Superposition state of N quantum states 0000..., 1000..., 01000..., etc.
- 2N (complex) coefficients are required to describe the superposition

Source: McKinsey analysis, expert interviews, press search
Methodology

Quantum computing temperature and industry positioning (pp 6-7)

- The quantum computing temperature (pp 6) is based on a survey across +300 industry leaders globally and their opinion on the impact of quantum computing on their respective industry
- The impact estimation and impact share across quantum capabilities (pp 7) is based on a survey across +100 McKinsey experts and industry leaders

Quantum computing player landscape and investment (pp 3, 4, 8-14)

- To obtain the Quantum Computing player landscape, we considered the following entities
  - Startups: founded in the last 25 years with estimated revenues below 200 million USD
  - Incumbent companies: companies with revenues above 200 million USD
  - Hardware manufacturers are considered such, if they have already demonstrated the creation of a quantum computer or have announced efforts in this direction
  - Systems, software and algorithms include all companies and startups which develop dedicated software or applications for quantum computing. Hardware manufacturers which also develop dedicated software solutions are also included in this group
  - Investments in startups has been extracted from Pitchbook and Crunchbase and amended by McKinsey analyses
  - We could not obtain high-quality data on the quantum computing landscape in China due to most quantum efforts being kept secret.