Quantum Computing: Finding Its Place in the Advanced Computing Sector

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Currently, the Promise of QC is Substantial

- QC systems have the potential to exceed the performance of conventional computers for problems of importance to humankind and businesses alike in areas such as:
  - Physical Simulation
    - Materials science
    - Chemistry
    - Pharmaceuticals
    - Oil and gas
  - Machine learning
  - Optimization
- And the list grows longer each day
- Goal: Demonstrate so-called quantum supremacy using a programmable quantum device to solve a problem that no classical computer can solve in any feasible amount of time
  - For example: Factoring a large number into its two prime integers

Shor's Algorithm: *The* QC Exemplar

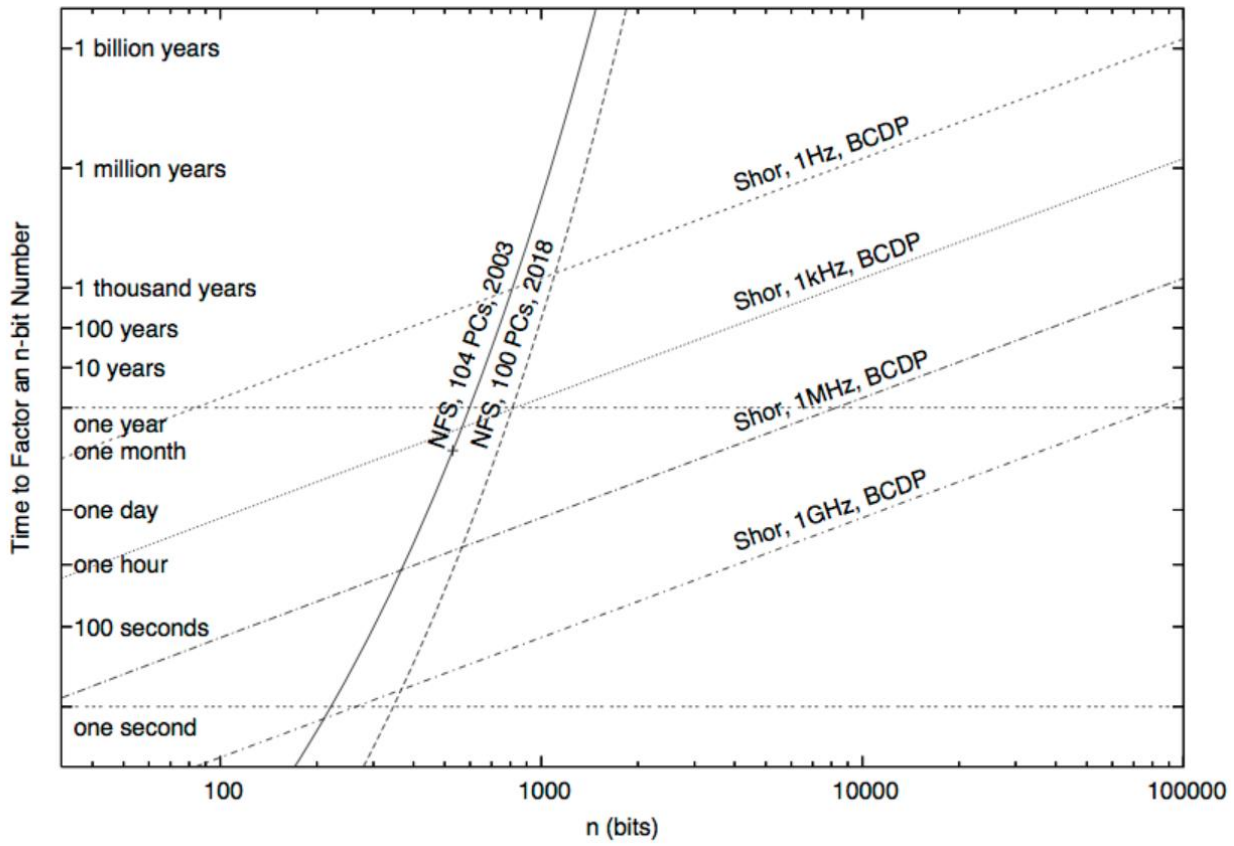


Figure 1. Scaling of number field sieve (NFS) on classical computers and Shor's algorithm for factoring on a quantum computer, using BCDP modular exponentiation with various clock rates. Both horizontal and vertical axes are log scale. The horizontal axis is the size of the number being factored.

- Prime Number Factoring
  - 15 = 5 * 3
- *Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer,* Peter W. Shor (AT&T Research) 1995
- Graph from *Architecture Dependent Execution Time of Shor's Algorithm*, Rodney Van Meter et al, 2006

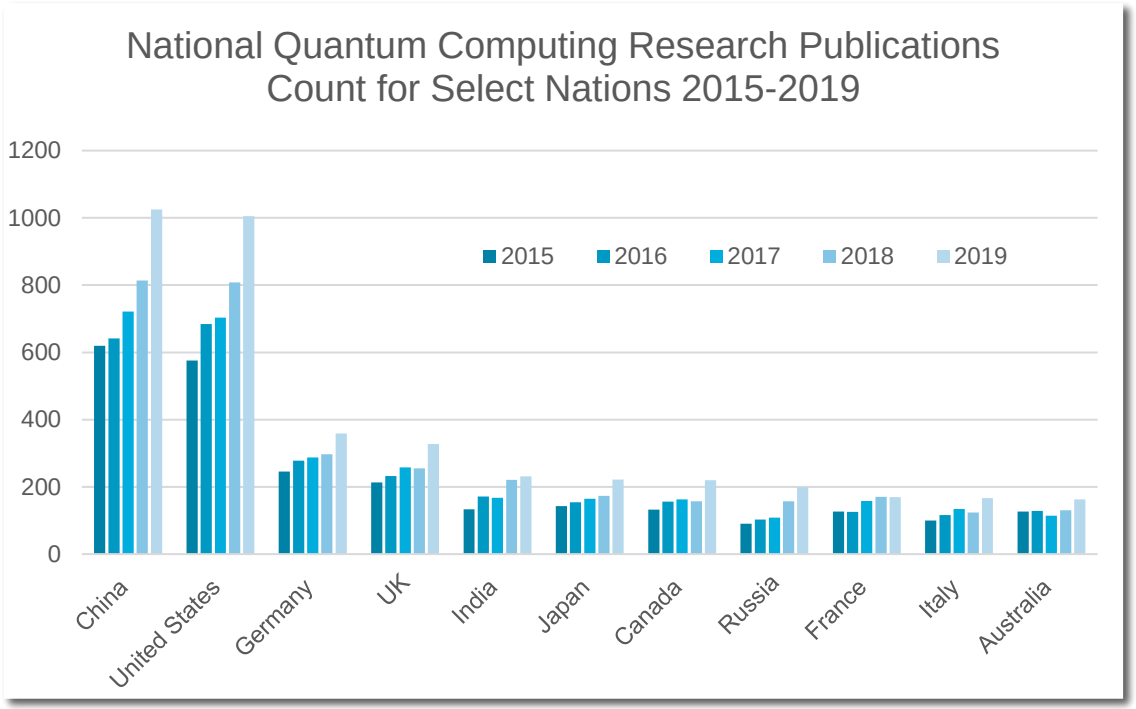
Substantial Challenges Ahead

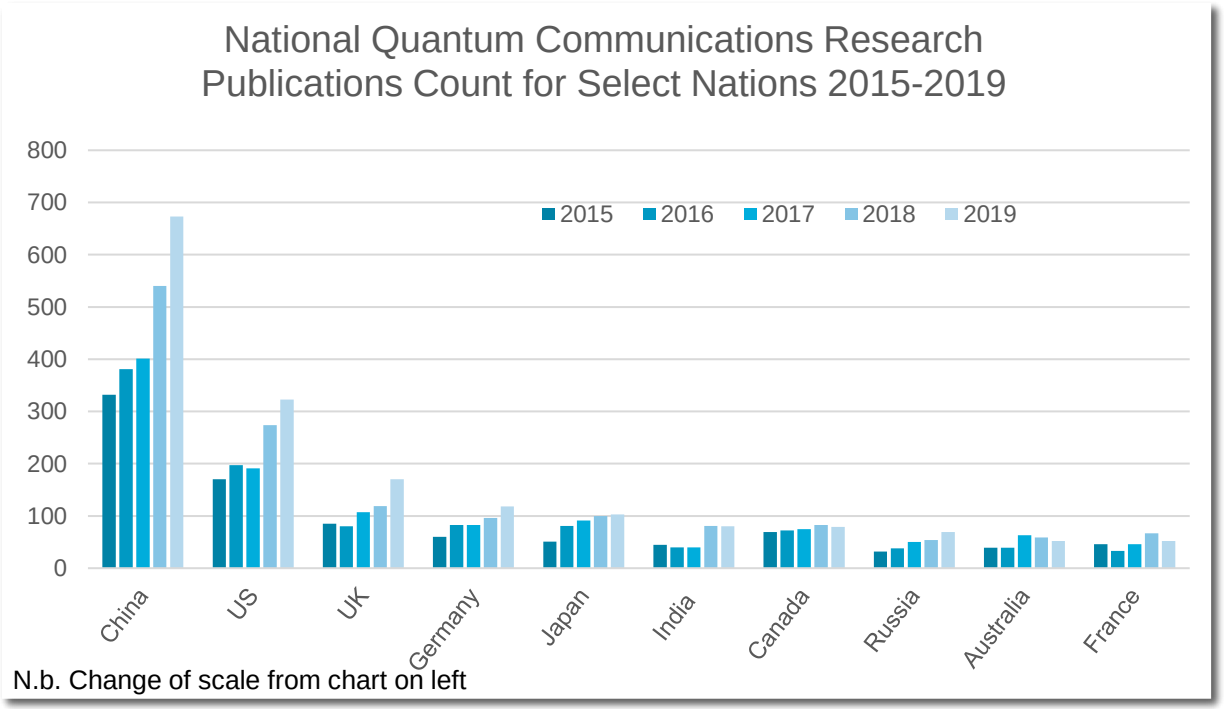
- Formidable technical issues in QC hardware and software
- Uncertain performance gains
- Unclear time frames
- Disorganized progress in algorithm/application development
- Looming workforce issues

All these factors complicates treating QC as a stable market alongside more traditional IT sectors

- Making a business case is tough...but it needs to be done

Comparisons of National-Level Quantum Computing and Communication Research Publications 2015-2019





N.b. Change of scale from chart on left

- Summary of leading R&D publications between 2015 and 2019, using the following query to search a publication's title, abstract, and keywords
- Query: "quantum comput*" OR "qubit" OR "quantum simulat*“ where * represents wildcard letters
- The search, conducted on May 21, 2020, yielded a total data set of 15,230 documents

- Summary of leading R&D publications between 2015 and 2019, using the following query to search a publication's title, abstract, and keywords
- Query: "quantum communicat*” OR “quantum key distribution” OR “QKD” OR “quantum crypto*”where * represents wildcard letters
- The search, conducted on May 21, 2020, yielded a total data set of 6,530 documents

Select National/Regional Government Quantum Programs

- Canada: Quantum Science Funding Framework
- China: Key National R&D project, Quantum Control and Quantum Information
- EU: The Quantum Flagship
- France: Quantum: the technological shift that France will not miss
- Germany: Government Framework Programme for Quantum Technologies
- Japan: Q-LEAP
- Russia: Digital Economy National Program
- UK: National Quantum Technologies (UKNQT) Programme
- US: National Quantum Initiative Act

A Growing Collection of Quantum Computing Hardware Suppliers…

- **A wide and diverse range of QC hardware suppliers have emerged to populate a growing QC ecosystem**
  - Legacy Players (D-Wave, IBM, Atos)
  - Integrated Player (Honeywell)
  - New Entrants:
    - Pure Play: IonQ, Rigetti, ColdQuanta, Quantum Circuits Inc, Xanadu, IQM, etc.
    - Component Players: Intel
  - Non-traditional Players (Alibaba, AWS, Baidu, Google, Microsoft)
  - Myriad Stealth Players

Google, Microsoft, and AWS?

- AWS
  - Amazon Braket - CSP for Rigetti, IonQ, D-Wave
  - Amazon Quantum Solutions Lab (QC application development)
  - AWS Center for Quantum Computing (TBD, w/CalTech et al)
- Google
  - Quantum Processor – Sycamore Processor (53 qubits)
  - TensorFlow for Hybrid classical/quantum AI algorithms
- Microsoft
  - Azure Quantum - CSP for Honeywell, IonQ, Quantum Circuits
  - Quantum Network – Quantum Broker
  - Quantum Developers QKD
  - Topological Qubit Development

…and QC Software Suppliers Abound

	D-Wave	Google	IBM	Microsoft	Rigetti
1QBit	X		X	X	X
Boxcat			X		
Cambridge Quantum Computing		X	X	X	
Entropica Labs			X	X	X
Grid			X		
GTN				X	
Horizon Quantum Computing					X
HQS Quantum Simulations		X		X	X
JoS Quantum			X		
Labber Quantum			X		
Max Kelsen			X		
MDR	X		X		
Multiverse Computing				X	
NetraMark			X		

	D-Wave	Google	IBM	Microsoft	Rigetti
OTI Lumionics	X			X	X
ProteinQure	X		X	X	X
QC Ware	X	X	X	X	X
Q-CTRL			X		X
Qu & Co			X		
Quantastica					X
Quantum Benchmark		X	X		
Qulab				X	X
QxBranch	X		X	X	X
Rahko			X	X	
Riverlane Research				X	X
Solid State AI			X	X	
Strangeworks			X	X	X
Zapata Computing		X	X	X	X

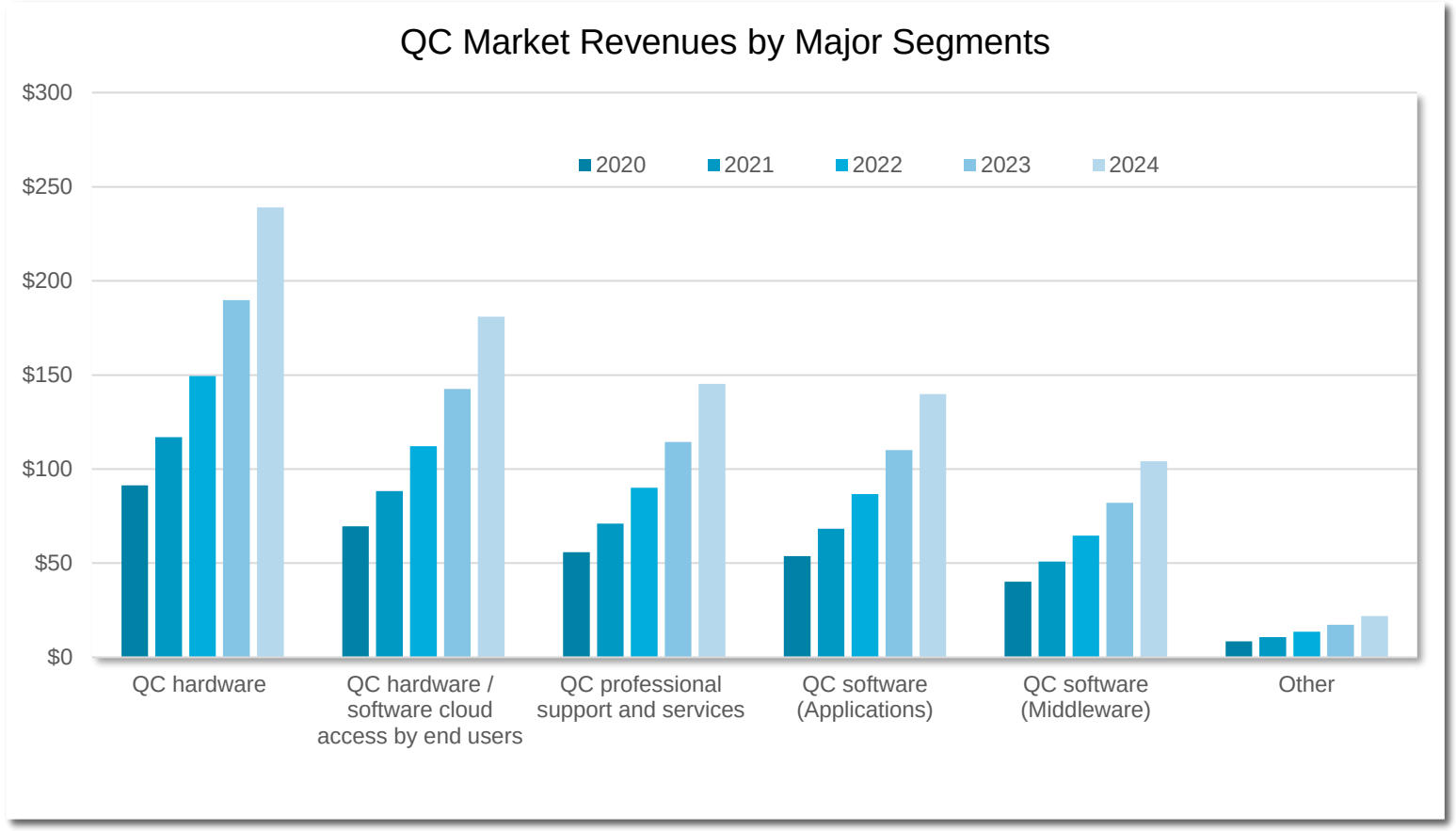
Source: Quantum Computing Report

QC Market Forecast Executive Summary

- The global QC market was worth about $250 million (+/- $30 million) in 2019
- Based on an anticipated CAGR of 27% between 2020 and 2024, the global QC market will grow from approximately $320 million in 2020 to $830 million in 2024
- On-prem and cloud access QC hardware will comprise about 50% of the global QC market for the next three years
- Optimization, physical simulation, and machine learning will near equally divide the algorithm space
- NISQ will be the near-term architecture of choice, followed by quantum annealers and digital simulators
- User access to QC will be primarily through the cloud, at three times the rate of an on-premise option

Building a QC Market Projection

Total QC Market Will Grow from $320 million in 2020 to Approximately $830 million by 2024



$ Millions

Items to Consider for Future and On-going Adjustment:

- Growth in QC on-prem hw (+/-)
- Role of quantum simulators (+/-)
- QC cloud pricing models (+/-)
- In-house vs professional support (+/-)

QC Buyer/User Performance Considerations

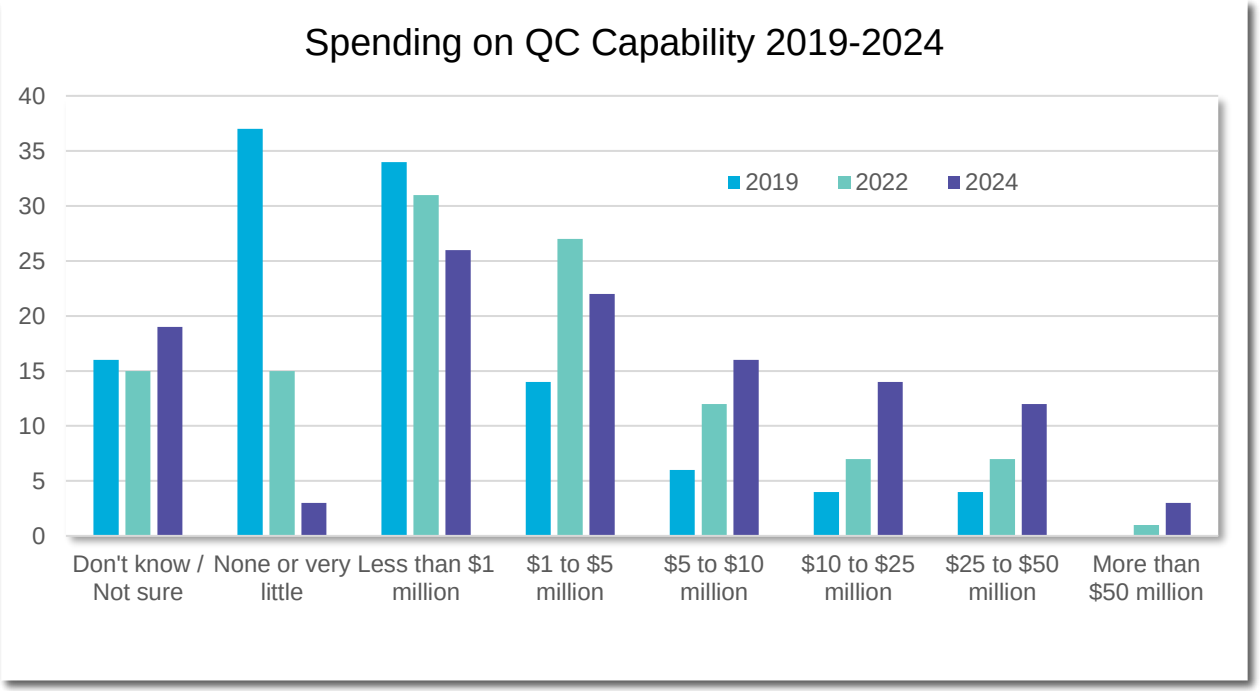
QC Performance Expectations: Modest Gains Prevail

What is the minimum application performance gain you would require to justify using quantum computing for your existing and planned workloads?		
	Number of Responses	Percent
2-5X	9	7.8%
5-10X	14	12.2%
10-50X	26	22.6%
50-100X	30	26.1%
100-250X	11	9.6%
250-500X	3	2.6%
Greater than 500X	4	3.5%
Application or required performance not possible on classical systems	18	15.7%
n = 115		
Source: Hyperion Research, 2020		

- Expectations for the minimum QC performance gains for both existing and planned workloads were relatively modest
  - 78% of respondents would see a performance boost of less than 250X as justification for using QC
  - 42% would only need 50X or below
  - 20% would need less than 10X
- A 50X performance improvement translates into a roughly 4-5-year lead over counterpart classical computing performance
- Only 18 respondents (16%) would require true quantum supremacy or quantum-only applications to justify using a QC for their existing or planned workloads

QC Buyer/User Spending Plans

Anticipated QC Spending 2019-2024



- All companies intend to spend the same or more per year in quantum computing between 2019-2024
- Between 2019 and 2020, the percentage of respondent with little of no QC capability declines from 32% to less than 3%
- Between 2019 and 2024 the number of companies spending $25 million or more on QC goes from 4 to 17
- Using average price bands and number of companies in each price band, the total contribution to the QC sector from the 115 respondents will be
  - $324 million in 2019
  - $616 million in 2022
  - $1.06 billion in 2024

This represent a 27% CAGR for 2019-2024 total QC expenditures of the QC buyer/user respondents

How This Plays Out Near-Term

- Near-term QC Ramp Up
  - Many exploring applications/use cases and not just for traditional HPC but for enterprise IT computing environments
  - QC/SME application development could be next crucial milestone
  - That the market will be growing – at least for the next few years - is demonstrated
- Quantum computing is not a replacement for classical computing, but a companion technology
- The sector is not at the Moore's Law stage
  - Development is happening in many dimensions and in parallel:
    - Hardware (qubit, QC-Lan, architecture)
    - Software (middleware, applications, use cases)
    - Algorithms
    - Hybrid classical/quantum systems
    - Quantum inspired hardware and software

HYPERION RESEARCH

QUESTIONS?

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“Let me go check my quantum computer for any new email.”

--Will say no one, ever