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By: Davey Jose and Henry Ward

SPOTLIGHT

Quantum Computing Age

Multi-sector disruption

Quantum computing could be as transformational for the global economy as the internet, TV or telephone

The power to solve hugely complex problems would disrupt every industry, creating new opportunities – and risks

We explain key tech, developers, investors, and applications in an addressable market set to reach USD97bn by 2032

This is a Free to View version of a report with the same title published on 05 October 2022.
The original report focuses on how quantum computing could be transformational, discusses why investments into this new technology are so high, and looks at real-life applications happening today as they relate to our Nine Investment Themes.
Please contact your HSBC representative or email AskResearch@hsbc.com for more information.

HSBC quantum computing ecosystem

Understanding quantum bits, or qubits

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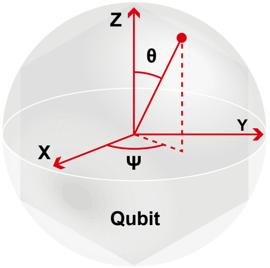
Classical bits are binary and can hold only a position of 0 or 1 …



… quantum computers (QCs) however, operate using **quantum bits called qubits**. These can be simultaneously 0 and 1, otherwise known as a superposition of all possible states. QCs have the potential to be as **transformational as the internet, TV and the mobile device**

Quantum computing is seeing big funding pledges

QC government funding (USDbn)

USD15.3bn
Mainland China

USD6.85bn
EU

USD1.85bn
US

How quantum computing could interconnect with sector applications and our key themes

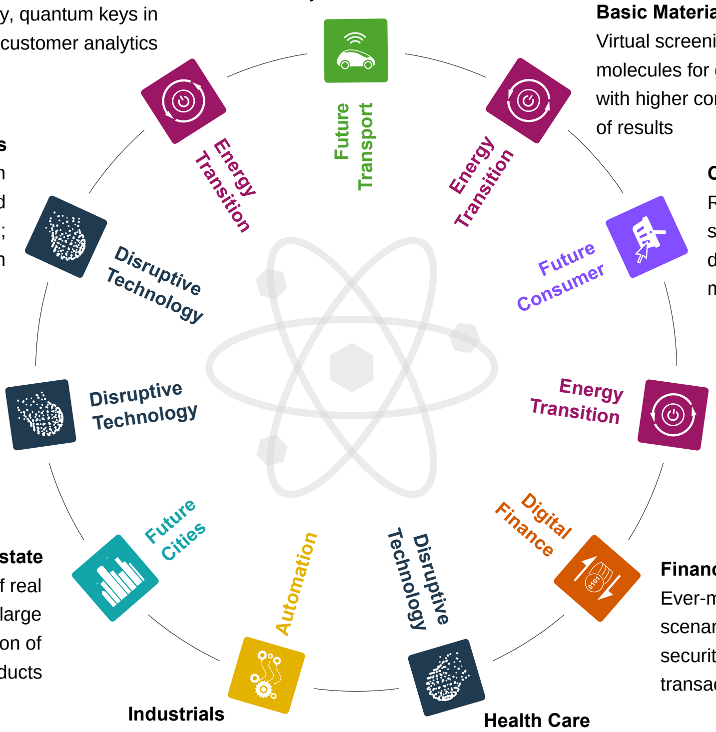
Autos
Optimisation may help yield efficiencies across production, supply-chain management, and mobility/traffic infrastructure

Utilities
Quantum grid to optimise input and output of energy, quantum keys in cybersecurity, customer analytics

Basic Materials
Virtual screenings of millions of molecules for given applications, with higher confidence in accuracy of results

Telecommunications
Highly secured encryption of communications and digital transactions; network optimisation

Consumer Staples
Real-time consumer insights, supply chains optimisation, demand fluctuations and fleet management



Technology
Semiconductor materials discovery and chip design. Build and design of quantum computers and chip architecture

Energy
Smart-grid optimisation to find perfect balance between reliability, availability, efficiency and cost

Real Estate
Improved modelling of real estate market with large datasets, and optimisation of mortgage products

Financials
Ever-more accurate market and scenario calculations, with higher security in payments and transactions

Industrials
Optimised industrial transport routes and supply-chain management in construction and aerospace

Health Care
Help with diagnostics, screening, and treatments. Faster R&D will improve drug design, protein folding predications and patient outcomes

USD480m
Quantum computing market size today …

USD19bn
… estimated market size by 2032 (40% CAGR)

USD97bn
Estimated total addressable market of QC applications by 2032

Source: US Department of Energy, ExxonMobil, Microsoft, Toshiba, PsiQuantum, Cambridge Quantum, Boehringer Ingelheim, Volkswagen, D-Wave, Geant, Honeywell, HSBC

QCs disruption potential

- Quantum computers (QCs) have the potential to be as transformational as the internet, TV, telephones, and railroads – disrupting society and industry
- Though a universal QC may be further out, QC-based applications exist today and are likely to grow in the near term
- We take a look at the potential disruption today and into the future, the levels of investments going into the space and possible risks the technology could bring

Big potential

Leap towards quantum age?

A giant leap forward in technology
In the coming decade, quantum computers (QCs) could very well be on the edge of disrupting industry and society, potentially for the better. As the quote by the venture capital (VC) firm Bessemer Venture Partners (BVP) below outlines, there is this growing belief within technology circles that the development of QCs is at a tipping point. If this happens, then one could say that society will transition from the "digital" to "quantum" computing age.

> **"By the end of this decade, QCs will be a trillion time more powerful than the most powerful supercomputer on earth today… the immense computational power that QCs can unleash will lead to *life-changing medicines, more accurate weather forecasts, smarter AIs, longer lasting batteries, safer space travel, sustainable energy sources*, and benefits society has yet to even discover.**
>
> **Bessemer Venture Partners, 17 August 2020**

Potential applications

The promise of QCs…
The potential disruptive implications are vast. Below we highlight just a small glimpse of the type of innovations corporations are working on today with QC technology. With these application examples, we also highlight which of the 9 HSBC Global Research themes – Automation, Demographics, Digital Finance, Disruptive Technology, Energy Transition, Future Cities, Future Consumer, Future Transport, Lower for Longer – we believe it could impact via.

- **Automotive:** A Japanese automotive components manufacturer used QC to optimise the control of automated guided vehicles (AGVs) on its factory floors. It was able to reduce the amount of time each AGV spent waiting for a clear route by 15% on average, even when prioritising safety over speed. **#Automation #FutureCities #FutureTransport**
- **Banks:** In 2020, a British bank used QC to trial their algorithm to see how much the bank should set aside for bad loans, they discovered that a process that typically takes weeks "was done in seconds and provided a better answer", according to their Global Head of Innovation[1]. **#DigitalFinance**
- **Energy:** A Japanese software company and a large Japanese real-estate developer used QC to develop sustainable cities via optimised waste management and lower CO_2 emissions. The route for collecting waste was reduced from 2,300km to 1,000km and as a result CO_2 emissions were cut by 57%. **#EnergyTransition #FutureCities**
- **Retail:** A Canadian supermarket chain used QC on grocery optimisation solutions. The supermarket was able to reduce the time of an important optimisation task from 25 hours to 2 minutes of calculations per week. **#Automation #FutureConsumer #FutureCities**

Where are QCs today?

Making a universal QC – scale from unstable to stable qubits – is difficult

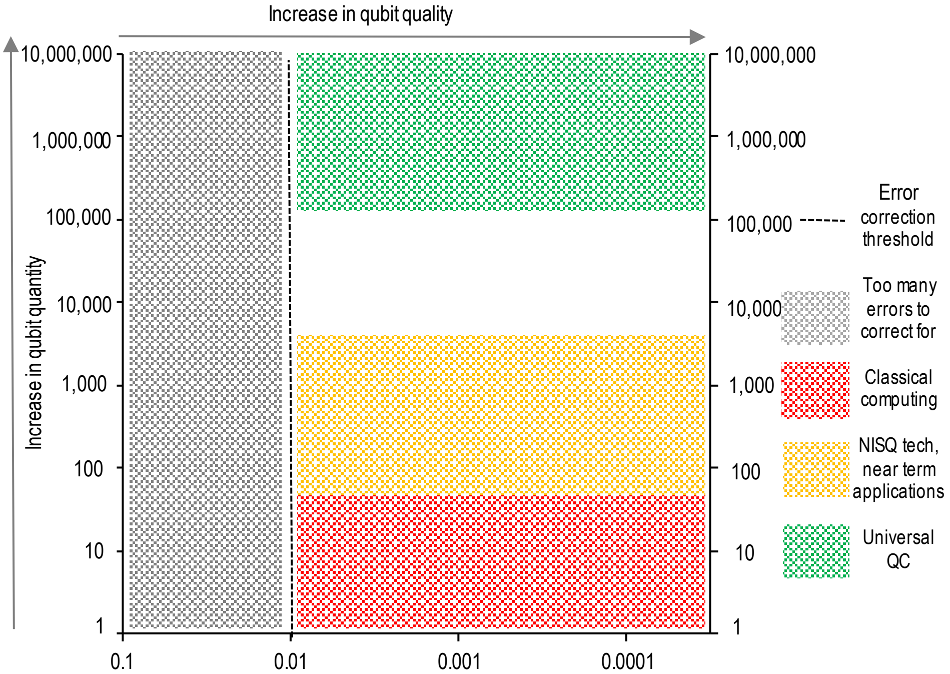
Simplifying a complex idea, QCs work on the notion of something called "qubits" (quantum bits). The more stable qubits a system has, the more powerful it can be. Generally speaking, the more powerful QCs today have double to triple-digit number of qubits, albeit unstable qubits. For example, IBM has a QC system with 127 qubits. These type of QCs can execute complicated calculations but the applications are still limited and narrow in scope.

The objective for QC companies is to scale the number *usable* (e.g. so called fault-tolerant) qubits into the order of hundreds, thousands and eventually millions, to create more a powerful QC system – or a so called universal QC. These systems would then be able to solve more commercial applications with a wider scope – solving tasks which can't be done on a traditional computer today.

However, we must highlight that the universal QC currently does not exist yet – only milder versions of a QC system are in play today, as we highlighted above. We are currently in what technologists call the noisy intermediate-scale quantum (NISQ) era, where qubits have high error rates and have to be error-corrected. But these systems are already having commercial applications. See below chart, which gives a visual representation of classical computing, today's NISQ era versus the ultimate goal of QCs – to achieve fault tolerant and high number of qubit powered QC, or a universal QC.

[1] How RBS made a quantum leap into the future, The Times, 5 July 2020

1. Qubits quantity vs quality visualisation…



Source: HSBC, Google
Note: NISQ (noisy intermediate-scale quantum)

It must be noted, that due to varying levels of qubit instability today, not all quits are made equal either. So the QC industry is beginning to adopt a metric called quantum volume (QV), which enables a more apples-to-apples to comparison between different QC systems. We go into more detail on how QC systems work, the different types of QC technologies and the issues they have to overcome to be scalable – see chapter A brief guide to QCs on page 15.

Big risks

Threat to cybersecurity and digital infrastructure

Keep it secret, keep it safe

For all its potential benefits, however, the development of QCs may also bring new risks. One could be its impact to cybersecurity through breaking modern cryptography. Cryptography and encryption today works by creating difficult maths problems such as integer factorisation and discrete logarithms. They are used in the encryption of valuable commercial and often sensitive personal data, which classical computers take an immensely long time to solve, meaning the data is safe from prying eyes with the current technology stack.

The risk is that fully scaled QC systems might be able to break these complex problems very quickly. For example, when a universal fault-tolerant computer breakthrough is achieved, a commonly used encryption technique called RSA could potentially be rendered breakable by implementing Shor’s algorithm (a QC algorithm for integer factorisation).

Lose data today, get data exposed in the future

Regardless of the timeline of QCs, patient hackers could collect data that they cannot decrypt now and wait for the day the technology becomes available. Therefore, if firms have data that needs to stay sensitive 20-30 years into the future, losing data today, even if it can’t be decrypted at present, could be just as damaging as losing it later.

This is why making data QC-era proof might be a more pressing issue, especially with the rise of ransomware and data theft, as we outlined in *Age of cybersecurity*, 29 April 2021. On the other hand, companies like BT and Toshiba are building secure communications from site to site, using quantum secure technologies.

Will it disrupt blockchain infrastructure?

Is QC a threat to decentralised tech?

Another potential threat posed by QCs is to blockchain technologies. These are typically powered by highly quantitative oriented concepts such as 'proof-of-work' or even 'proof-of-stake' technologies. Decentralised blockchain technologies often use 'miner' programs – operated by multiple users across multiple systems – to solve intricate cryptographic puzzles, making it very difficult if not impossible for one user to control the ecosystem. QC systems in theory could be deployed using a so-called 51% attack of the network or hijacking the key signature system[2].

In other words, it would theoretically be possible for one user with a QC to 'own' a blockchain ecosystem and hence centralise it (in effect), negating a key perceived benefit. However, this is somewhat mitigated by the fact it is unlikely only one person would have a QC without anyone else having one too.

Making blockchains quantum safe…?

Despite the potential danger presented by future QC technology for blockchain applications, a number of experts have claimed the threat can be mitigated. For example, The Nationwide Analysis Council of Canada working with the College of Waterloo have teamed up to explore ways of making blockchains quantum-safe[3].

A number of companies are also beginning to develop solutions, with some working on quantum security technology "which can be applied to any blockchain network"[4].

Regulatory risks

QC standards and regulations are on their way…

The University of Portsmouth have looked into what regulation of QCs might look like[5]. They identify that before effective regulation can be put in place, governments need to get educated on quantum technology and its effects. Otherwise policymakers will be unable to identify key risks, create standards and codes of conducts suitable for the QC age.

The University also identified that regulation would be more effective if done at an international level to prevent low standards. There is also the need to agree a common language and definitions in order to create legal certainty. This aspect is currently being explored by the institute of Electronic and Electronics Engineers Standards Association[6].

Act now?

The World Economic Forum (WEF) has recognised that a fault-tolerant QC will be able to break most public-key encryptions[7]. But despite the threat being perhaps 10-15 years away, the WEF say that firms and institutions should start to prepare today, as hackers are storing encrypted data today, waiting for QCs to become available to decrypt the data at a later date.

There are already signs that regulation and standards are on the way. In the US the National Institute of Standards and Technology (NIST) is developing standards fit for the quantum era and will publish them in the next couple of years. However, any standards will need to evolve as quantum computers evolve too. The WEF has also highlighted the EU's OpenQKD (Quantum Key Distribution) project as a great example of developing standards ahead of the quantum era.

Or wait for future standards?

Additionally, the UK's National Cyber Security Centre (NSCS) has cautioned against firms adopting non-standardised quantum-safe cryptography (QSC)[8], as it is complex and expensive and there is a high risk that the security level may be unverifiable if products are not based on a standard algorithm. The NSCS points to NIST and the European Telecommunications Standards Institute (ETSI) as two institutions working on guidance for the QSC transition. The NSCS recommends that companies wait for the findings of these institutions in order to effectively manage the transition.

[2] "Ethereum won't hide from quantum computers behind PoS shield", Cryptonews, 24 April 2021
[3] Crypto and Quantum Computing – Is It A Threat?, Ledger, 10 July 2020
[4] Cryptocurrency faces a quantum computing problem, CNET, 12 November 2021
[5] An Overview of Quantum Computing and how it can be Regulated, University of Portsmouth, 11 February 2021
[6] IEEE Approves Standards Project For Quantum Computing Definitions, IEEE SA
[7] Quantum computing will change the cyber landscape, here's why we need proper governance, World Economic Forum, 28 February 2022
[8] Preparing for Quantum-Safe Cryptography, National Cyber Security Centre

HSBC's proprietary Disruptive Technology framework

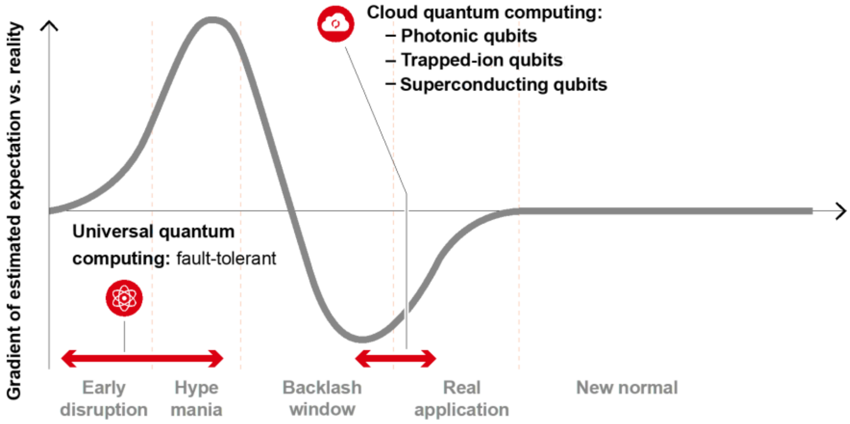
We place Cloud QCs in the backlash to real applications phase of our framework…

Many state-of-the-art QC systems today are actually accessible via cloud service models, or even directly from the QC provider. This is enabling enterprise end users and researchers to build and test optimisation issues and tackle real world problems, as we outlined in the opening of this chapter.

These QC clouds enable users to access a variety of QC hardware technologies including superconducting, trapped-ion and photonic qubits. But let us be clear, no system commercially available today is a universal QC. We place the already available cloud QCs between the 'backlash' and 'real applications' window today in the framework we use to understand disruptive tech.

HSBC's proprietary Disruptive Technology framework: The Quantum Computing Age

2. HSBC's proprietary Disruptive Technology framework: The Quantum Computing Age



Source: HSBC

Though universal QCs remain in the early disruption phase

We believe that due to the complexities and unsolved hardware issues, universal QCs are still in the 'early disruption' to 'hype mania' phase of our disruption framework. Much R&D needs to be done before universal QCs can be implemented successfully at all, let alone on a commercial scale, but the funding and time needed could well materialise in the coming decade due to the global efforts being made within QC research from big tech, SPACs, start-ups to governments.

A brief guide to QCs

- We outline the basics of QC and the different types of technology currently available
- Today's QC systems, usually accessed via the cloud, are good at solving complex optimisation problems and advanced simulations
- Tomorrow's 'universal' QC promises immense power, capable of solving an entirely different class of problem – but building it presents major technological hurdles

The basics of QCs

> **Nature isn't classical… and if you want to make a simulation of nature, you'd better make it quantum mechanical**
>
> **Richard Feynman, Theoretical Physicist (1918-1988)**

Over the coming few pages we attempt to give a basic primer on QCs and provide a flavour of the technologies involved, which we believe will be helpful when trying to evaluate the QC world. We examine six key questions:

- What do we mean by quantum computing?
- How mature is quantum computing today and where is it going?
- What are the key emerging qubit technologies?
- What are the main types of QCs today?
- What problems can quantum computing solve?
- Are firms ready for QCs?

We also explore the principles of quantum entanglement and superposition, which underlie the technology's vast potential.

What do we mean by quantum computing?

No QC PhD, no problem!

Understanding QC technology fully probably needs a quantum computing related PhD, but few readers will have the bandwidth to combine such an endeavour with the day job. So over the coming few pages we attempt give a basic primer on QCs and a flavour of the technologies involved, which we believe should be useful when trying to evaluate this space.[9]

[9] We at HSBC Global Research wish to thank our colleagues in HSBC's Innovation team (Steve Suarez - Head of Innovation, Mekena Metcalf PhD and Phil Intallura PhD) for helping us understand and explain the complexities of the QC space for this report.

From zeros and ones…

To put today's computing technology in context, the readers of this report will most likely be accessing it through a "classical computer", which operates using electronic signals to represent bits of information, either a 0 or a 1. Over time, classical computers have become faster as engineers have reduced the size of the components in chips and shortened the distance electric signals travel between components[10].

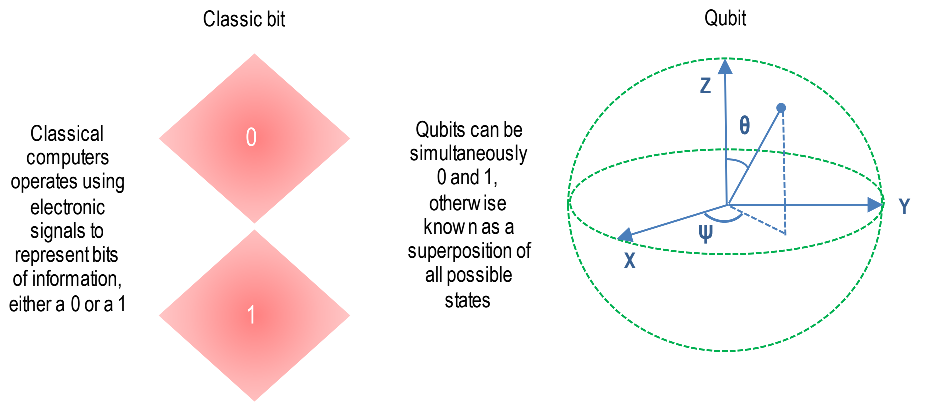
To qubits…

QCs, by contrast, operate using quantum bits called qubits. These can be simultaneously 0 and 1, otherwise known as a superposition of all possible states. There are two key properties of QCs and qubits – entanglement and superposition. These principles can be a bit mind-bending for non-experts, and we attempt an explanation, but the essential point is that these properties enable QCs to do things significantly faster than traditional computers we use today.

Road towards the universal QC but first commercial quantum advantage

The long-term goal for QCs is to become capable of solving problems even the most powerful supercomputers today cannot. In our view this ability to solve a new class of currently insoluble problems is a defining feature of next-generation, so-called 'universal' QCs. However, there may also be "quantum advantage" applications over the next few years, where QC systems significantly speed up processes a classical computer can already handle. See chart below for a QC timeline created by the HSBC Innovation team in our Global Functions department, whose team members who do indeed have QC PhD expertise.

3. A visualisation: Classical "bit" based computers to quantum "qubit" systems



Source: HSBC

Where are we today in QCs and where are we going?

What is the NISQ era? The punch card and vacuum tube era of QCs…

At present, we are in what is sometimes called the noisy intermediate-scale quantum (NISQ) era. This is when quantum states are much more vulnerable to errors than classical computers. A so-called "decoherence" arises when the environment interacts with the qubits, causing them to lose their quantum state, meaning the information they store is lost. To put it simply, some QC systems require exceptionally low temperatures and still conditions to work, and malfunction when they get too hot, or are subject to a breeze.

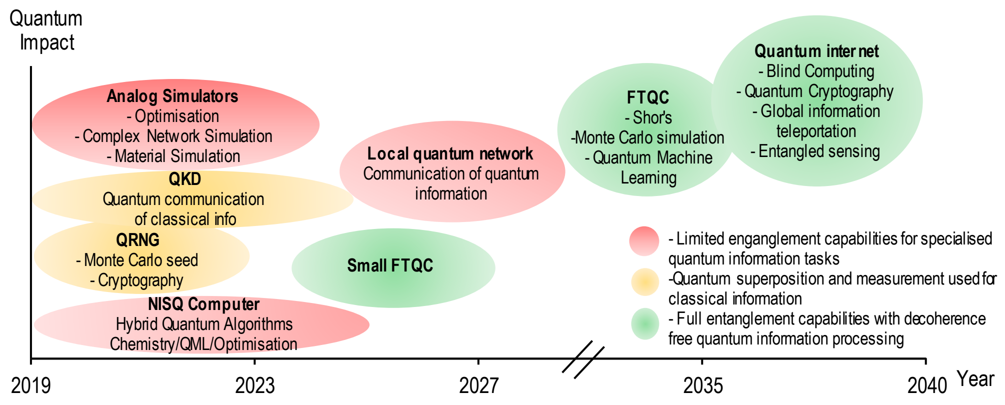
So although the types of systems available today are called QCs, they remain early in the evolution cycle of the technology. In a way, today's QCs are like a 1950s computer system using punch cards and vacuum tubes. It's still a computer by definition, but it's crying out for the modern transistor to achieve its full potential.

And the race is already on to take the next step. Instability in the QC system can be caused by factors such as radiation, light, sound, heat, or magnetic fields. To overcome this problem, the system needs to use quantum error correction, which protects quantum information (i.e. quantum states) from environmental interactions. By and large, today's QC systems are error-corrected QC systems.

[10] Going beyond Moore's law with quantum computing, Huawei

A key next step in the technology's evolution would be 'fault-tolerant' QC – systems which are less affected by decoherence. The development of higher-quality qubits, and systems with greater numbers of qubits – in the thousands, rather than the hundreds – would help achieve this goal, but both present major technological challenges.

4. Timeline to a universal QC …



Source: HSBC Innovation team, Global Functions

Note: Quantum Key Distribution (QKD), Quantum Random Number Generator (QRNG), Fault Tolerant Quantum Computing (FTQC), Quantum Machine Learning (QML)

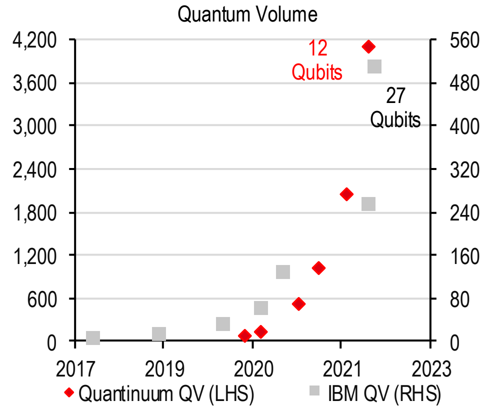
Beyond the qubit metric… quantum volume

Moore's law to quantum volume

HSBC's Innovation team believe that when evaluating a quantum computing system there are several metrics to consider. This not only includes the number of qubits but also other factors such as the quality of the qubits, the survival time of the qubits, and the quality of entangling operations between the qubits. See chart 11 which highlights some of the factors contributing to a QC system.

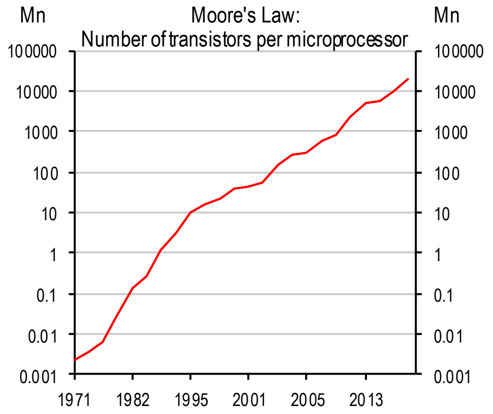
In the modern digital computer age, Moore's law has been one of the easier and transparent ways to track computer improvements, with the number of transistors per microprocessor doubling roughly every two years. In the QC age, HSBC's Innovation team says, a new metric that encompasses both the qubit number and other operation qualities will be used, namely a single number metric called the "quantum volume". This term was popularised by IBM towards the end of the 2010s. Generally speaking, the larger the quantum volume, the better the quantum device.

5. IBM and Quantinuum (Honeywell) been broadly tracking Moore's law …



Source: HSBC, Quantinuum, IBM, Forbes, Quantum Insider

6. … as per the number of transistors per microprocessor since 1971



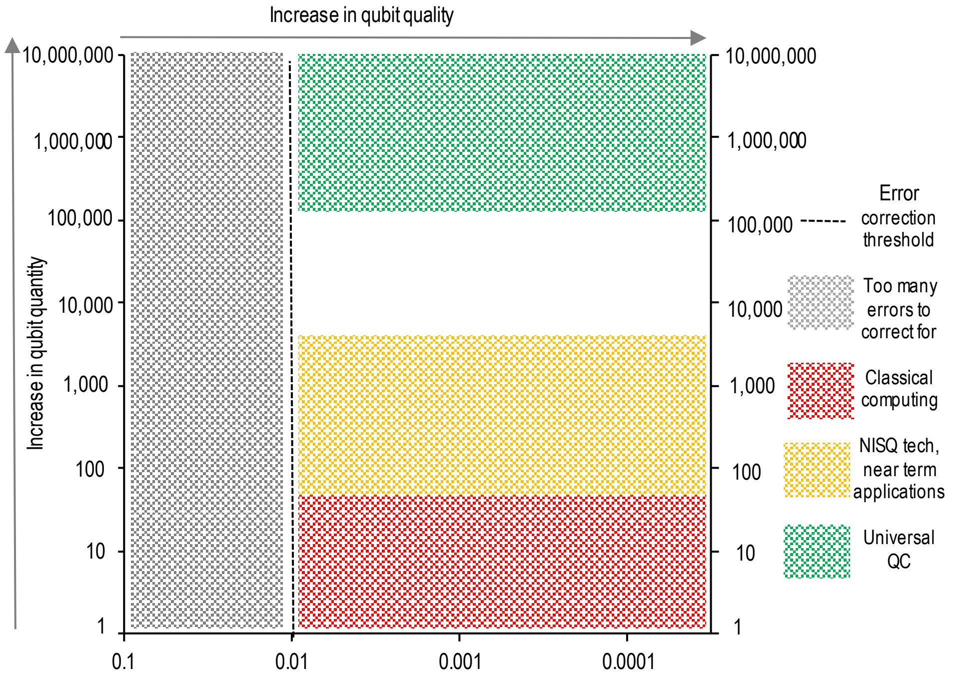
Source: Our World In Data

Note: Logarithmic scale

True QCs requires fault tolerant qubits

The HSBC Innovation team further says that scientists and engineers are developing methods to mitigate error to get the most of out of near-term QCs. As we outlined earlier, however, they say that true quantum advantage requires fault tolerant qubits.

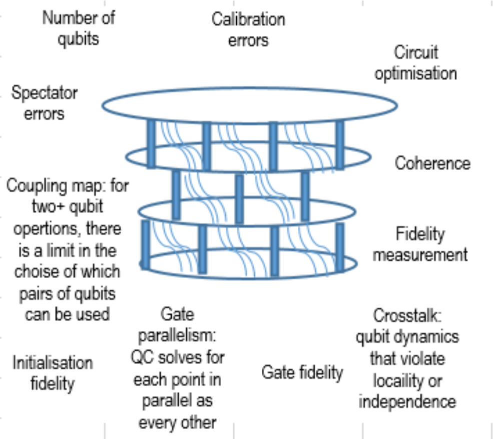
7. Qubits quantity vs quality visualisation…



Source: HSBC, Google
Note: NISQ (noisy intermediate-scale quantum)

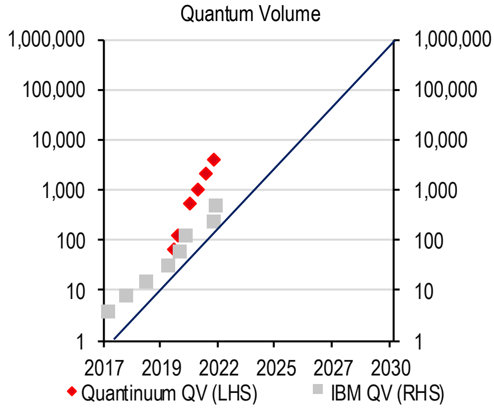
HSBC's Innovation team says currently, Quantinuum – demonstrated the largest quantum volume and is on track to demonstrate small scale FTQC (fault-tolerant QCs) calculations. Google have articulated the quality of qubits along with the number of qubits required to go beyond classical computing capabilities. The HSBC Innovation team say that achieving a large number of high quality qubits is a very challenging problem, and different developers are pursuing a range of potential solutions.

8. Factors contributing to quantum performance …



Source: HSBC, IBM

9. … QV would breach the 1m mark by 2030 if it follows Moore's law



Source: HSBC, Quantinuum, IBM

Key quantum qubit technologies

Currently there are a number of different approaches to develop QCs. It currently remains an open race to see which wins to become the equivalent of the transistor, which powered the classical computing revolution. However, we believe there are three leading technologies worth understanding:

1. Superconducting qubits

Favoured by the big tech firms

Many of the large listed technology companies tend to be favouring superconducting technology to develop their QC offering. In fact, one of the largest QCs ever made to date is IBM's 127-qubit QC called the Eagle. Google have claimed to have achieved quantum advantage in 2019 also using superconducting technology.

The promise of scalability

At this point in time, superconducting qubits are believed to be the most promising means of scaling up to make a large quantum processor. This results in three types of qubits: charge, flux, and phase qubits. Some of the advantages of superconducting qubits are that they have fast gate times – that is, they can carry out operations very quickly. And the technology behind superconducting qubits is based on existing practices and knowledge, which makes scaling superconducting QC systems easier to envisage than with other methods[11].

Large, complicated to cool and needs error correcting…

But one of the drawbacks of this method is that it requires refrigeration to near absolute zero temperate in order to function. For example, IBM's quantum processors are at about a hundredth of a degree above absolute zero[12]. There are other issues too: for example superconducting qubits are relatively large and only maintain their quantum states for short periods of time, and so therefore demand error-correcting techniques. Other key challenges are maintaining high coherence and high-fidelity control across a large quantum hardware.

2. Trapped-Ion qubits

Uses magnetic fields to trap ions

Ions are atoms which have gained or lost one or more electrons and thus have an electrical charge. In layperson's terms, ion trap devices literally trap ions using magnetic fields and hold them in place.

Operate at room temperature and stable for longer

Advantages of this approach are that ion traps can store quantum information with longer coherence times and possess a high degree of stability. Ion trap computers can also operate at room temperature, though they work better when cooled.

Slower than superconducting and tech not mature

However, there are drawbacks to the approach. For instance, the computers are much slower than superconducting computers. The technology involved in creating ion traps is also not as mature and therefore it may take longer to see large improvements in scalable systems.

3. Photonic qubits

Light as information carrier and operates in range of temperatures

Photonic qubit technology uses photons/particles of light as the information carrier. They have long coherence times, can operate equally well in cryogenic and room temperatures, and have weak interaction with the environment.

Could power quantum internet through fibre-optic

Photonic qubit systems are also compatible with existing fibre-optic telecommunications infrastructure, which may help enable powerful quantum networks and even a quantum internet[13].

Possible scaling issues…

However, whilst CAS has claimed quantum advantage, the set-up was bulky and the number of photons lost during operations suggest scaling up will be very difficult[14]. The computer was also not reconfigurable – meaning it could only execute a single algorithm.

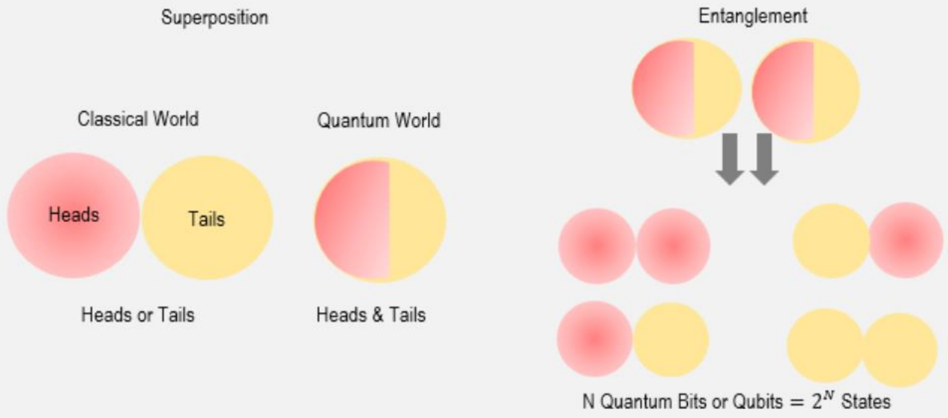
[11] Introduction to Qubits: Part 2, The Quantum Insider, 3 November 2019
[12] What is quantum computing?, IBM
[13] In the race to hundreds of qubits, photons may have "quantum advantage", IEEE Spectrum, 5 March 2021
[14] In the race to hundreds of qubits, photons may have "quantum advantage", IEEE Spectrum, 5 March 2021

Key qubit property explained: entanglement, superposition

Earlier in the report we mentioned entanglement and superposition of qubits. Below is a bit more colour on what that means and why it's important for QCs.

Entanglement: Two or more particles interact such that their quantum states become correlated, and remain so no matter how far apart they are[15]. Thus, we can use the measurements from one qubit to draw conclusions about the others. By adding just one more qubit into a system, QC systems can calculate exponentially more information and solve more complex problems[16].

10. Superposition and entanglement chart…



Source: HSBC, Intel

Superposition: In superposition, quantum particles are a combination of all possible states. They fluctuate until they're observed and measured[17]. Unlike in a standard bit, a qubit can store the 0 and 1, but also a superposition, a linear combination of them. The two values are coexisting and being processed at the same time[18].

Another popular way to visualise superposition is the Schrodinger's cat experiment. The idea is that if one places a cat in a sealed box with a poison that has a 50/50 chance of killing the cat. After a period of time the cat can be said to be both dead and alive, in a superposition of states until the box is opened and the act of observation randomly determines whether the cat is dead or alive. See below chart to visualise.

The difference between physical and logical qubits

Physical qubits such as in one of the sections above, for example supercomputing or trapped-ion qubits, these are unstable and are subject to decoherence. To mitigate this, many physical qubits are used with the purpose of keeping the quantum state stable over time. These sets of physical qubits are called logical qubits. For each physical qubit used in a computation, other qubits are being used for identifying and corrections errors.

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[15] A Quantum Revolution, Canadian Institute for Advanced Research, April 2021
[16] What is quantum computing?, Microsoft Azure
[17] What is quantum computing?, Microsoft Azure
[18] 2021 Quantum Threat Timeline Report, Global Risk Institute, January 2022

Types of quantum computers

Today we classify QCs into three broad categories:

Low hanging fruit and working today

1. Quantum annealer

A quantum annealer is the easiest QC system to build but is the weakest and most restrictive. Its computational power is no more than that of a classical computer but they are very good at solving optimisation problems. D-Wave Quantum is focusing on quantum annealing and has worked with Google and Volkswagen to conduct a quantum experiment to manage traffic flows in Beijing. The algorithm successfully reduced traffic by choosing the ideal path for each vehicle.

The point of quantum advantage…

2. Analog quantum (AQ)

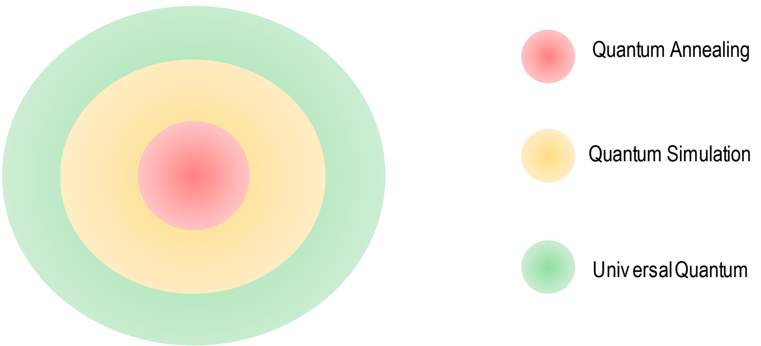
This is where the current crop of QC development is. Analog quantum is much faster than classical computers and this is where you will begin to start seeing quantum advantage take place. Applications include chemistry, materials, optimisation problems, sampling, and dynamics. It is a more difficult QC to build than a quantum annealer but comes with many more benefits.

The holy grail of QC

3. Universal quantum

This is by far the most difficult level of QC to build, but if it can be done, it would be revolutionary. Its disruptive applications include: secure computing, machine learnings, cryptography, chemistry, materials, sampling, searching, dynamics, and much more. These computers could eventually have in excess of 100,000 qubits[19] and require massive amounts of energy to power[20].

11. Venn diagram of key types of QC …



Source: HSBC
NB: Larger the circle, the more powerful and greater number of possible applications. Larger the circle, more difficult to implement and hence longer time to commercial product.

[19] The 3 Types of Quantum Computers and Their Applications, Visual Capitalist, 14 March 2016
[20] How Much Power Will Quantum Computing Need?, IEEE Spectrum, 5 October 2015

Beyond the hype: what types of problems can QCs solve today?

Today there are two broad types of applications QC systems could be deployed for:

1. Solving complex optimisation problems and
2. Deploying advanced simulations

Quantum optimising algorithms…

1. Solving complex optimisation problems

The first use cases of QCs could be to solve complex optimisation problems, which try to find the best way to juggle many variables in order to maximise a particular outcome. For example, many companies' main goal is to maximise profits given a number of constraints: cost, quality, time, etc. Quantum optimisation algorithms can help to optimise complex networks like *traffic flows*, *airport congestion*, *deliveries*, *energy flows*, and perform risk/reward calculations for financial portfolios. Whilst classical computers are able to handle some of these tasks, they are can be substantially slower than a QC because they can't work with as many variables simultaneously, and instead essentially operate by trial and error.

Reduces range of possible outcomes quickly…

QCs may not necessarily be able to find the exact most optimal result but they will be able to drastically reduce the range of possible best outcomes to a relatively small handful of options – and do so very quickly.

Could improve operating income by USD850bn by 2050

Boston Consulting Group estimates that QCs can improve the operating incomes of their users by between USD450-850bn by 2050[21]. A number of high profile companies and governments appear to have bought into the idea of utilising QCs for optimisation problems.

Simulation of complex molecules at the atomic levels…

2. Deploying advanced simulations

Another widely anticipated benefit **of QCs will be the ability to simulate complex molecules at an atomic level, bringing with it the possibility of** *new drug discoveries*, *battery technologies*, *chemicals*, and even *new materials*. A particularly intriguing and important early application for quantum simulators is that they may help to design the very technology they need to advance, for instance, quantum simulators may help to design room-temperature superconductors (a difficult thing to do), allowing electricity to be transmitted without losses for QC systems[22].

Finance will find quantum simulations useful

In particular, simulations can also be immensely helpful in finance; IBM has conducted research using quantum algorithms to outcompete conventional Monte Carlo simulation for assessing financial risk. As a result many financial institutions have invested in quantum computing start-ups and partnered with big tech firms[23].

In 2020, a British bank used QC to trial their algorithm to see how much the bank should set aside for bad loans, they discovered that a process that typically takes weeks "was done in seconds and provided a better answer", according to their Global Head of Innovation[24].

But other sectors will gain too from QCs

According to a McKinsey report, pharmaceuticals, chemicals, automotive, and financial companies are on track to become the first beneficiaries of quantum advantages, with financial services and life sciences likely to generate the highest-value use cases from QCs over the longer term[25].

Some issues encountered by QCs for optimisation, simulation and more…

But are firms ready for QCs?

It is worth noting both for optimisation and simulation, that one potential problem for quantum computing is whether we can get enough accurate data inputs. After all, QC outputs are only as good as inputs.

[21] Commercialising quantum computers, The Economist, 26 September 2020
[22] Why all eyes are on quantum computers, The Economist, 9 March 2017
[23] What is quantum computing?, CB Insights, 7 January 2021
[24] How RBS made a quantum leap into the future, The Times, 5 July 2020
[25] Quantum computing funding remains strong, but talent gap raises concerns, McKinsey Digital, 15 June 2022

This also applies to a firm's ability to recruit talented staff. Quantum computing is a niche area of study and many firms have cited a lack of available talent as constraints to building universal QCs. McKinsey have identified that in December 2021 there were three times as many job postings for quantum related talent than there were annual quantum technology graduates at a master's level.

However, there are up to 350,000 graduates in "quantum-related fields" such as electrical engineering or physics, who could be upskilled to fill roles[26] – so there is a large pool of potential talent should firms choose to invest and upskill their staff.

A June survey, the "2022 Quantum Readiness" report, found that among 501 executives, 97% expected QCs to have a moderate to high degree of disruption in their sectors. Some 48% believing QCs will play a significant role in their company's activities by 2025. Nevertheless, the report also showed that only one-third had begun planning for commercialising quantum and less than one-quarter had a dedicated team to explore quantum's potential[27].

[26] Quantum computing funding remains strong, but talent gap raises concerns, McKinsey Digital, 15 June 2022
[27] How can you prepare now for the quantum computing future?, EY, 27 June 2022

Glossary of key terms

Key QC definitions

Decoherence: Decoherence arises when the environment interacts with the qubits, causing them to lose their quantum state.

Entanglement: Two or more particles interact such that their quantum states become correlated, and remain so no matter how far apart they are.

Logical qubits: Sets of physical qubits are called logical qubits.

Noisy intermediate-scale quantum (NISQ): At present, we are in the so called NISQ era. This is when quantum states are much more vulnerable to errors than classical computers.

Photonic qubits: Photonic qubit technology uses photons/particles of light as the information carrier, they have long coherence times, can operate equally well in cryogenic and room temperatures, and have weak interaction with the environment.

Physical qubits: To mitigate this against decoherence, many physical qubits are used with the purpose of keeping the quantum state stable over time.

Post-quantum cryptography (PQC): Using mathematical problems just as with existing forms of asymmetric cryptography to guard against cyber threats from QCs.

QCaas: cloud-based service that provides access via the cloud to QC platforms.

Qubit: QCs operate using quantum bits called qubits. These can be simultaneously 0 and 1, otherwise known as a superposition of all possible states.

Quantum advantage: QCs which significantly speed up processes a classical computer could do.

Quantum Annealer: using quantum physics to find low-energy states of a problem and this the most optimal or near-optimal solutions to complex optimisation problems

Quantum key distribution (QKD): Uses quantum properties of physical systems to protect against cybersecurity threats of QCs.

Quantum supremacy: QCs that solve problems that even the most powerful supercomputers cannot solve. Allows two parties to produce a secret key which is only known to the parties and is used to encrypt messages and decrypt them.

Quantum volume: measures the capabilities and the error rates of QCs and allows for comparisons between QCs, it measures the maximise size of square quantum circuits QCs can implement successfully.

Superconducting qubits: At this point in time, superconducting qubits are believed to be the most promising means of scaling up to make a large quantum processor. This results in three types of qubits: charge, flux, and phase qubits.

Superposition: In superposition, quantum particles are a combination of all possible states. They fluctuate until they're observed and measured.

Trapped-ion qubits: Ions are atoms which have gained or lost 1+ electrons and thus have an electrical charge. In layperson's terms, ion trap devices literally trap ions using magnetic fields and hold them into place.

Universal QC: A universal quantum computer promises a more complete knowledge of our environment, even at a molecular level. A universal QCs full potential is unknown and theoretical.

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