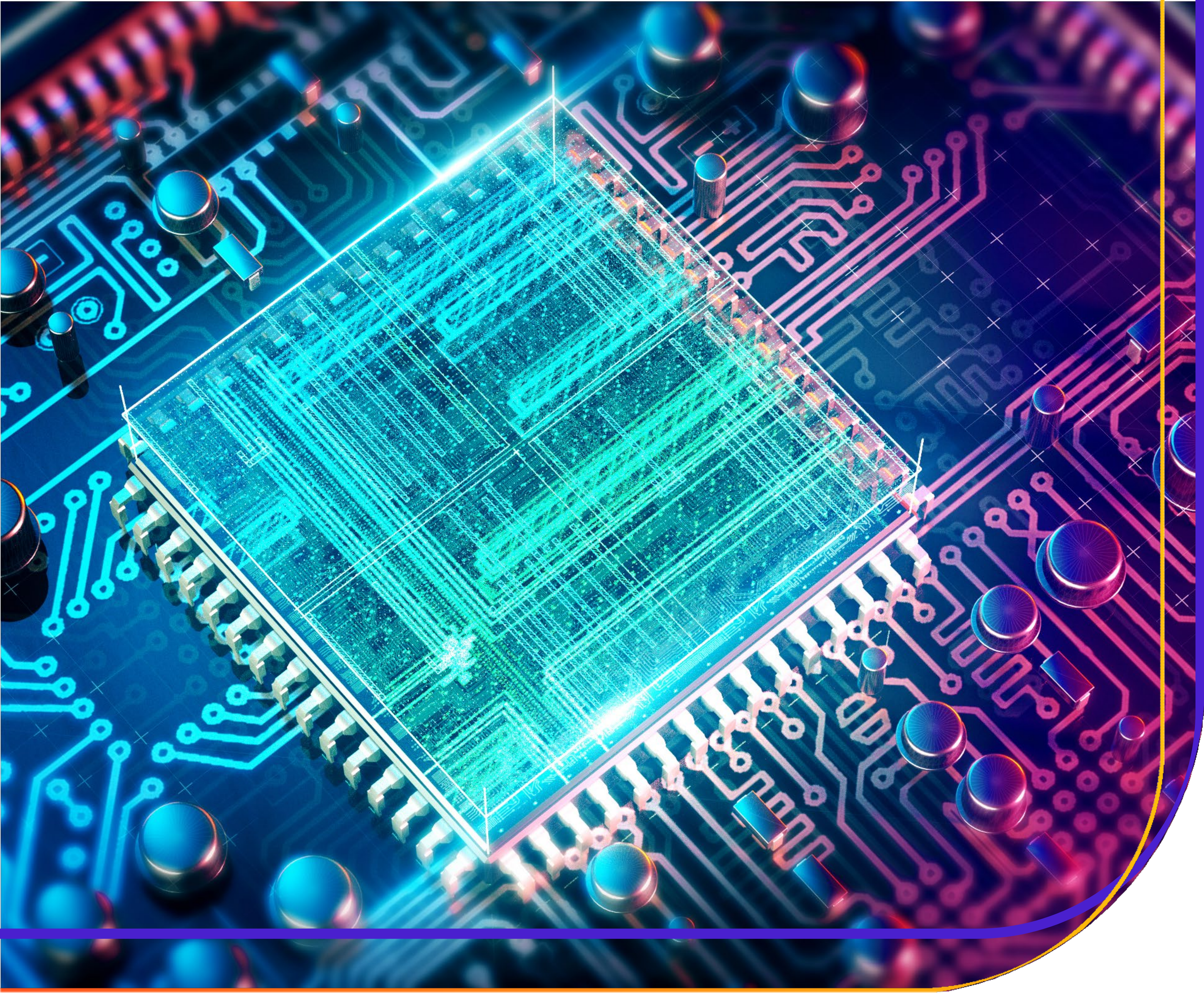

How can Saudi Arabia join the Quantum computing race?

Arthur D Little

وزارة الاتصالات وتقنية المعلومات
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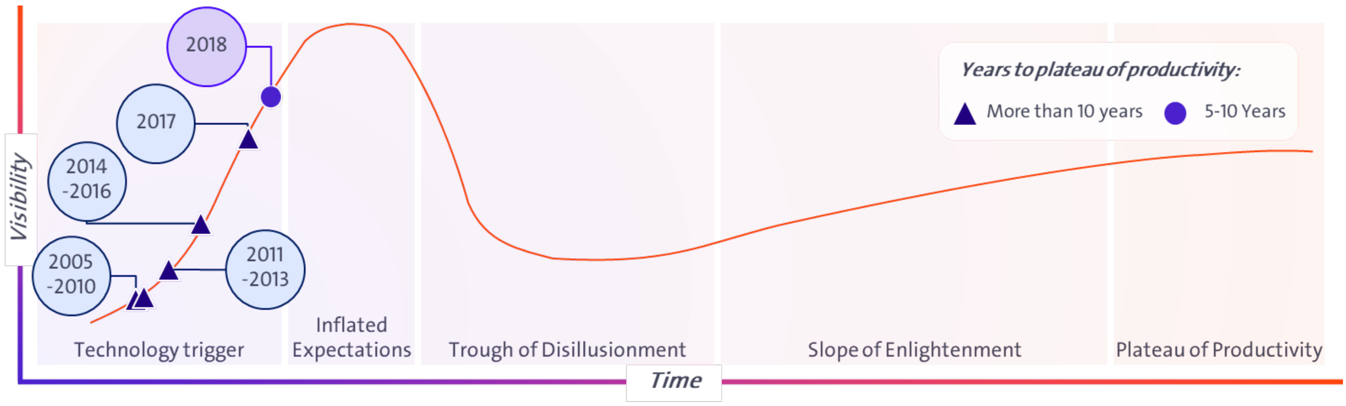
1 Executive summary

Quantum computing (QC) is moving quickly from an interesting, emerging technology to a priority for prominent research universities, pioneering companies across various industries as well as forward-looking governments. QC has the potential to solve problems that are currently unmanageable and spur innovation. This is due to its extremely fast computing speed and ability to process large volumes of data, as well as the complexity of the algorithms that it can support. At the same time, QC can make corporations and governments vulnerable to digital security attacks by breaking the methods of encryption that they currently rely upon. Significant technological breakthroughs are frequently being announced by universities and companies leading QC research, and an increasing number of patents are being filed every year across the world, demonstrating an exponential progress towards QC maturity. Therefore, delays in investing in QC may limit the long-term competitiveness when this technology becomes mainstream.

Early movers will be able to seize large shares of the potential market. Clearly, countries and companies lacking intellectual property (IP) and skills will not be able to play meaningful roles in the QC future. KSA should therefore not be a bystander and earn the “right to play” in this emerging field. Currently, QC hardware is far from maturity, faces significant technological challenges and requires large investments in R&D. Moreover, it is costly and complex to operate. For this reason, KSA should focus on quantum computing-as-a-service (QCaaS) opportunities and prioritize development of QC software and services capabilities. It should ensure that the right talent is developed and encourage Saudi companies to obtain the necessary tools to leverage QC’s full potential when the technology matures. This report outlines what KSA needs to do at strategic and tactical levels to compete and succeed in the QC race.

2 QC – Unprecedented potential for speed, volume and innovation

QC is an emerging reality. First included in Gartner's Emerging Technologies Hype Cycle in 2005, the quantum promise has been growing steadily. It is expected to be commercially available in the next five to ten years. (See Figure 1.)



Source: Gartner, Arthur D. Little analysis

Figure 1:QC in Gartner's Emerging Technologies Hype Cycle (2005–2018)

Supporting unprecedented capabilities around computing speed and volume, this fundamentally different technology is beginning to move from theoretical models to working prototypes. In October 2019 Google claimed "quantum supremacy" – solving in 200 seconds with a quantum computer a specific problem that would have required a significantly higher time[1] to address with the most powerful available supercomputer. Although the company and the scientific community recognize that this is still a very initial step with a narrow scope, it is undeniable that QC technology is approaching the known limits of classical computing, and similar and more meaningful milestones are anticipated in the near future.

Current QC development progress is expected to result in the following applications being available in the near term, delivering significant revenue generation, cost saving and/or enhanced security opportunities:

1. Optimization: QC can solve complex mathematical optimization problems for which computational requirements increase exponentially as ever-increasing variables are added. These include:
   - Finding a better way to manage risk in financial investment portfolios
   - Identifying the most cost-effective routes for shipping goods
   - Determining the most efficient ways to extract resources from mines
   - Developing innovative pharmaceutical drug discovery methods
2. Simulations in chemistry & physics: QC can play a key role in exploring nature at the smallest scale of atoms, subatomic particles and their interactions – fields which have often been beyond the capacity of traditional computing systems. QC can support modeling of the effects of chemical reactions in organic, inorganic and complex materials, or simulate physical problems such as the "many-body" theory around systems made up of many interacting particles[2]. These advances could have a huge impact on industries such as agriculture (new properties for fertilizers), energy systems (enhanced battery solutions) and healthcare (discovery of new drugs).
3. Artificial intelligence (AI): AI algorithms perform best when the machine learning (ML) algorithms used to train them are given massive volumes of data from different sets to classify and analyze. However, the precision and speed with which this information can be processed according to specific characteristics is one of AI's largest challenges. QC can provide record processing and speed capabilities to obtain "fine-grain" aspects from this data, leading to insights invisible to traditional computers. Leading companies are already exploring opportunities in the intersection of QC and AI. For example, Volkswagen and D-Wave systems have combined both technologies to develop a traffic management system which allows real-time passenger number prediction and route optimization.

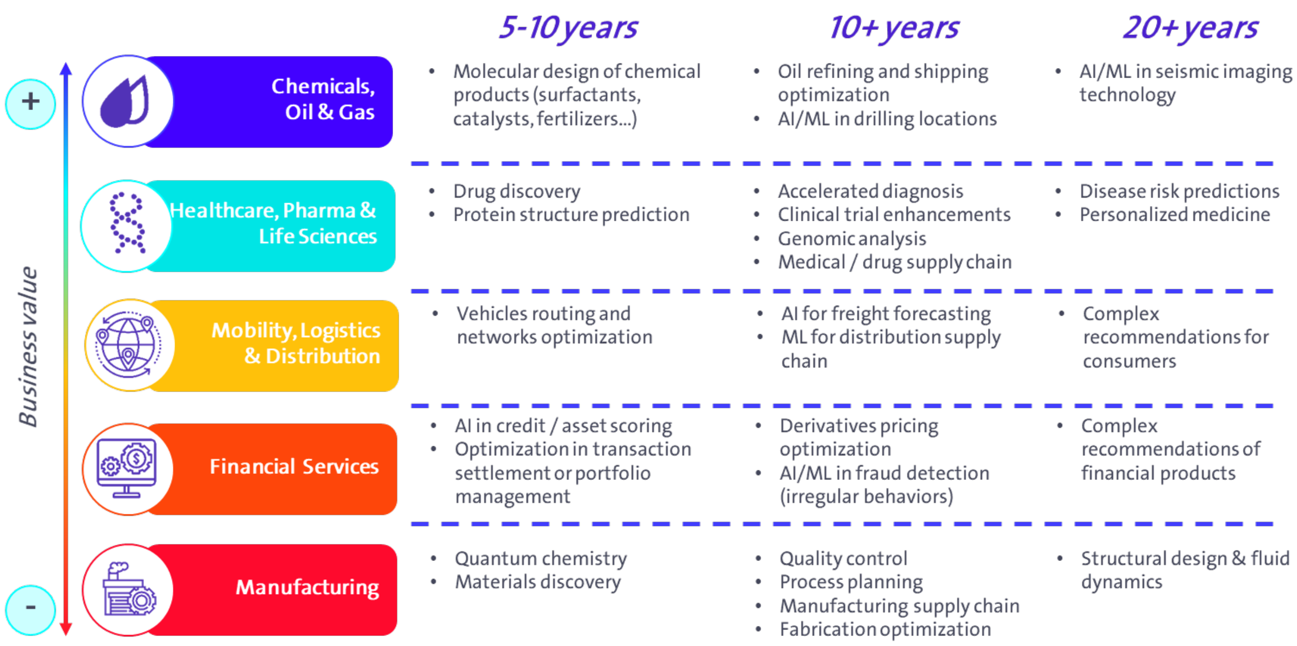
[1] Between 2.5 days (according to IBM) and 10,000 years (according to Google), based on article "On Quantum Supremacy", IBM, October 2019

[2] "Simulating quantum many-body dynamics on a digital quantum computer", Nature Magazine, November 2019

Currently at a pilot phase, Volkswagen intends to launch it commercially in the near term.

4. Security: Research has demonstrated that QC could break (or at least significantly weaken) the most elaborate existing encryption systems, thanks to its ability to try many possible keys simultaneously and find one that works – something beyond reach even for today's most powerful supercomputers. QC itself is a security solution, as information in quantum bits – or "qubits" – cannot be copied or deleted by anyone except the user who stored that information. Alternatively, quantum-proof, or "postquantum cryptography", is being consolidated as a simpler alternative to protect systems from potential quantum cyberattacks. This does not use quantum technology, but instead, mathematical techniques and algorithms (such as lattice-based or hash-based) that are just as hard to solve on quantum computers as they are with classical technology. In terms of security developing, QC experience will provide resilience for entities in both the private and public sectors. This is crucial, given the increasing importance of data and constant threat of cyberattacks.

Different innovation waves in QC are expected in the next couple of decades, with the impact felt across all industries. While precise economic returns are still hard to quantify, QC simulation use cases by chemical, energy and healthcare companies are expected to generate the greatest business value, followed by QC optimization projects carried out by mobility players. (See Figure 2.)



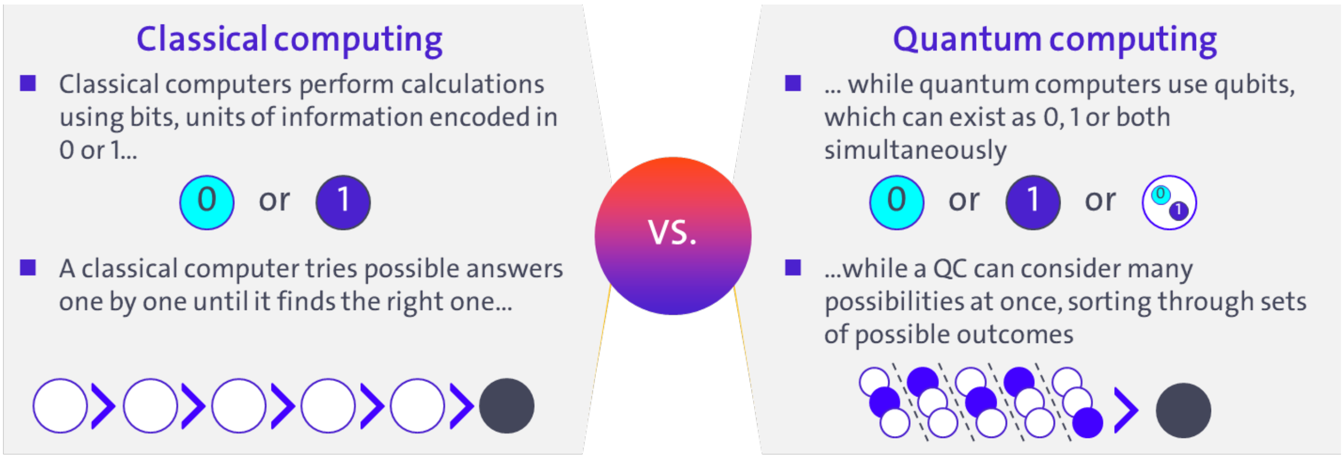
Source: IBM, quantumcomputingreport.com, Arthur D. Little analysis

Figure 2: Expected maturity and main potential use cases of QC

QC will unlock the possibility of addressing use cases that traditional computing cannot handle. However, it is not a substitute for the classical model. Excluding the cases listed above (and others yet to be discovered), classical counterparts will perform many operations as well as, or even better than, quantum computers in terms of cost and processing time. At least in the foreseeable future, both models will coexist, with companies and academia leveraging the best capabilities of each.

3 The technological breakthrough of QC

QC's technological revolution is best understood when compared to its classical counterpart. (See Figure 3.) As opposed to binary bits in classical computing, "qubits" leverage the ability of subatomic particles, such as electrons, photons and ions, to exist in more than one state at any time (0,1, or both simultaneously). This is known as "superposition" and allows each qubit to perform two calculations at once. Moreover, compared to bits that work in isolation, qubits can become quantum mechanically linked, or "entangled", acting as a group. When two qubits are entangled, QC can perform 2^2, or four calculations simultaneously; three qubits, 2^3 or eight calculations; and so on[3]. This exponential power increase tremendously enhances computing capabilities in terms of speed and volume and allows QC to solve problems traditional computing cannot. QC can perform certain tasks over a billion times faster than its conventional counterparts[4]. This means, for example, that problems as complex as solving integer number factoring (the basis of many existing advanced encryption systems) can be addressed easily with QC.



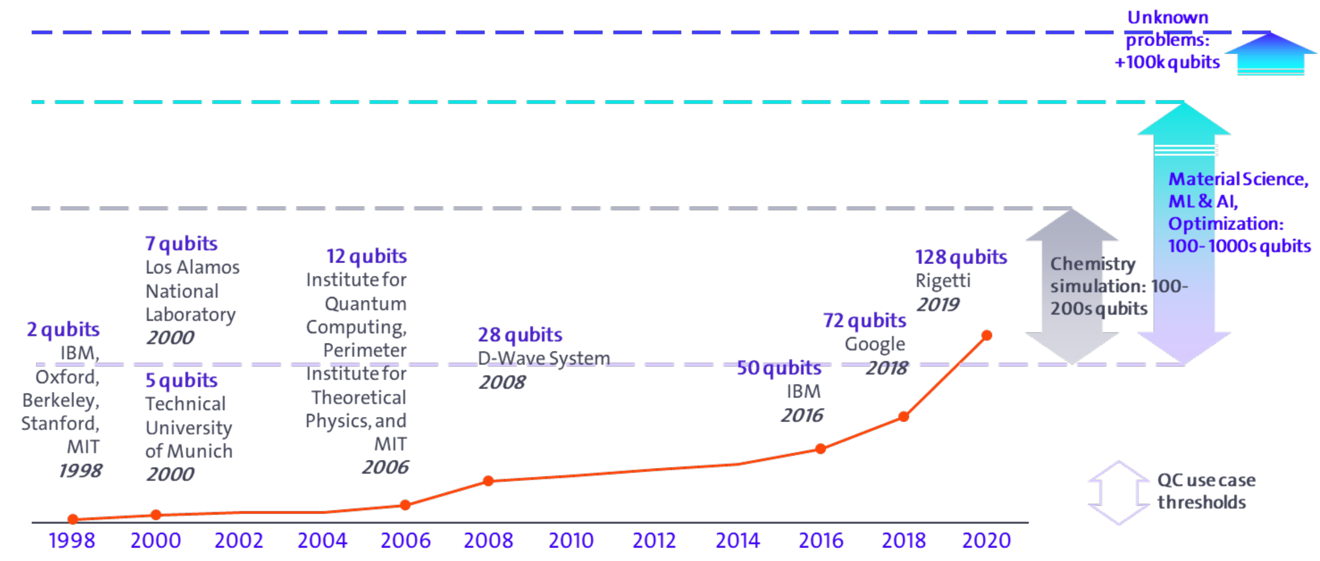
Source: Arthur D. Little

Figure 3: Classical computing versus quantum computing

As the capacity to solve ever-more complex and larger problems is directly linked to quantum computer's size, the scaling of entangled qubits is key to unlocking QC's full potential. Even though the concept of QC has been evolving for over 30 years, such scaling has recently been accelerating. (See Figure 4.) Just like the conventional "Moore's law[5]" paradigm seen in semiconductor processor development, "Rose's law[6]" for QC demonstrates a similar pattern in the relationship between the exponential power of QC and the speed at which it is growing.

However, as with many emerging technologies, progress from the research laboratory to industrial applications has been slow. While the current technology and fabrication process can be scaled up to ~10,000 qubits[7], going beyond that threshold into hundreds of thousands (or even millions of qubits) will require different technology and processes redesign. Despite this, QC hardware manufacturers claim there are ways in which this can be achieved, and do not see it as a fundamental obstacle. R&D will be key to continue progressing towards "quantum supremacy or advantage", i.e. reaching a level at which a quantum computer is superior to a traditional one in terms of time, cost and quality for specific use cases.

[3] "Sector Review: Quantum Computing", Hybridan LLP, February 2019
[4] Arthur D, Little estimates based on scientific publications, December 2019
[5] Moore's Law refers to the perception that the number of transistors on a microchip doubles every two years, though the cost of computers is halved, Investopedia, September 2019
[6] Term coined by Geordie Rose, founder of D-Wave Systems
[7] "Introduction to the D-Wave Quantum Hardware", D-Wave Systems, 2019



Source: CBI Insights, Gartner, Arthur D. Little analysis

Figure 4: Number of qubits achieved by date and organization, and initial QC use case thresholds

4 Investing in QC

Countries understand that they need to invest in QC sooner rather than later, both for cybersecurity reasons and to protect the competitiveness of their economies. Failing to do this will make it hard to overcome the barriers that are likely to be created by IP and talent scarcity. Demonstrating this current global trend, total government funding for QC R&D is estimated at USD 2.2 billion per year[8], and is growing, with new programs launched every year. (See Figure 5.) China's 2017 commitment to spending USD 11.4 billion of public investment on the National Laboratory for Quantum Information Services, which is currently under construction in the Anhui province[9], dwarfs the spend of other countries. The US, cognizant of the vital need to accelerate its QC efforts to maintain scientific and technological leadership, approved the "National Quantum Initiative Act" in late 2018, which sees an investment of USD 1.275 billion over 10 years [9]. Other leading countries (including the United Kingdom, the Netherlands, Germany, Singapore, Canada and the European Union as a whole) have recently announced additional QC investments.

Nation(s)	Initiative	Year	Investment, Time Frame	Scope
United Kingdom	UK National Quantum Technologies Program	2013	£270 million (US$358 million) over 5 years, beginning in 2014	Sensors and metrology, quantum enhanced imaging (QuantIC), networked quantum information technologies (NQIT), quantum communications technologies
European Union	Quantum Technologies Flagship	2016	€1 billion (US$1.1 billion) over 10 years	Quantum communication, metrology and sensing, simulation, computing, and fundamental science
Australia	Australian Centre for Quantum Computation and Communication Technology	2017	AUS$33.7 million (US$25.11 million) over 7 years	Quantum communication, optical quantum computation, silicon quantum computation, and quantum resources and integration
Sweden	Wallenberg Center for Quantum Technology	2017	SEK 1 billion (US$110 million)	Quantum computers, quantum simulators, quantum communication, quantum sensors; sponsored by industry and private foundation
China	National Laboratory for Quantum Information Science	2017	76 billion Yuan (US$11.4 billion); construction over 2.5 years	Centralized quantum research facility
USA	National Quantum Initiative Act	2018	US$ 1.275 billion USD over 10 years	Holistic program, with initiatives to develop quantum science, skills, infrastructure and ecosystem
Netherlands	QuTech	2019	€135 million (over 10 years)	Fault tolerant QC, Quantum Internet and Networked Computing and Topological QC

Source: The National Academy Press, Press, , Arthur D. Little analysis

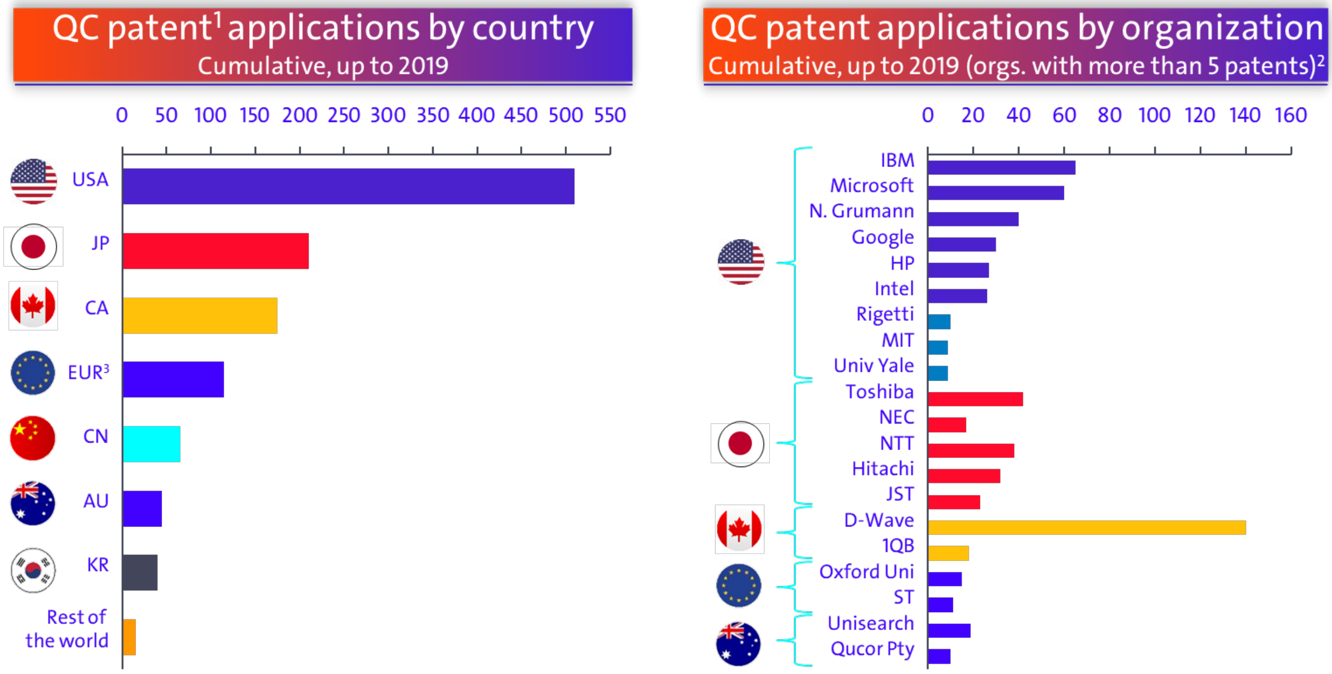
Figure 5: Selected publicly announced national initiatives in Quantum Science and Technology R&D, as of 2019

[8] "EU runs to catch up as governments pledge more cash for QC", Science Business Magazine, November 2018

[9] USA National Quantum Initiative Act, December 2018

While government spending is and will continue to be crucial to the successful development of QC (especially in the academic field), investment from private companies and venture capital will also play an important role. In 2017 and 2018 together, global private funding for QC was USD 450 million, compared to ~USD 100 million in the two previous years[10]. Leading tech companies such as Google, IBM, Intel and Microsoft are betting significantly on the development of QC, with undisclosed cumulative investments reaching billions of dollars. Moreover, venture capitalists are investing in specialized QC players such as Canadian company D-Wave Systems, which has received a cumulative investment of USD 177 million since 2012[11]. It is currently the world leader in the number of QC patents filed. (See Figure 6.)

The Middle East is also starting to take its first steps towards developing QC capabilities, with the UAE a first mover in launching QC-related initiatives. The Museum of the Future in Dubai will house the region's first quantum computer, in partnership with D-Wave. Additionally, in June 2018 the Dubai Electricity and Water Authority (DEWA) announced plans to work with Microsoft to develop quantum-based products to address energy optimization – an area where classical computers have serious limitations. This makes it the first organization outside the US to participate in Microsoft's Quantum program. In KSA, King Abdullah University of Science and Technology (KAUST), has begun QC research. Leading private sector players such as Saudi Aramco, which already uses supercomputer systems, could be potential QC investors.



Source: European Commission Joint Research Center, Arthur D. Little analysis
Notes: (1) Includes patents categorized as "Quantum Computing", having other related categories such as "Quantum Key Distribution", "Entanglement", etc. (2) Includes QC Top 20 Players, with 648 patents over 1149 (56% of total); (3) EU + Switzerland

Figure 6: QC patents by country and organization

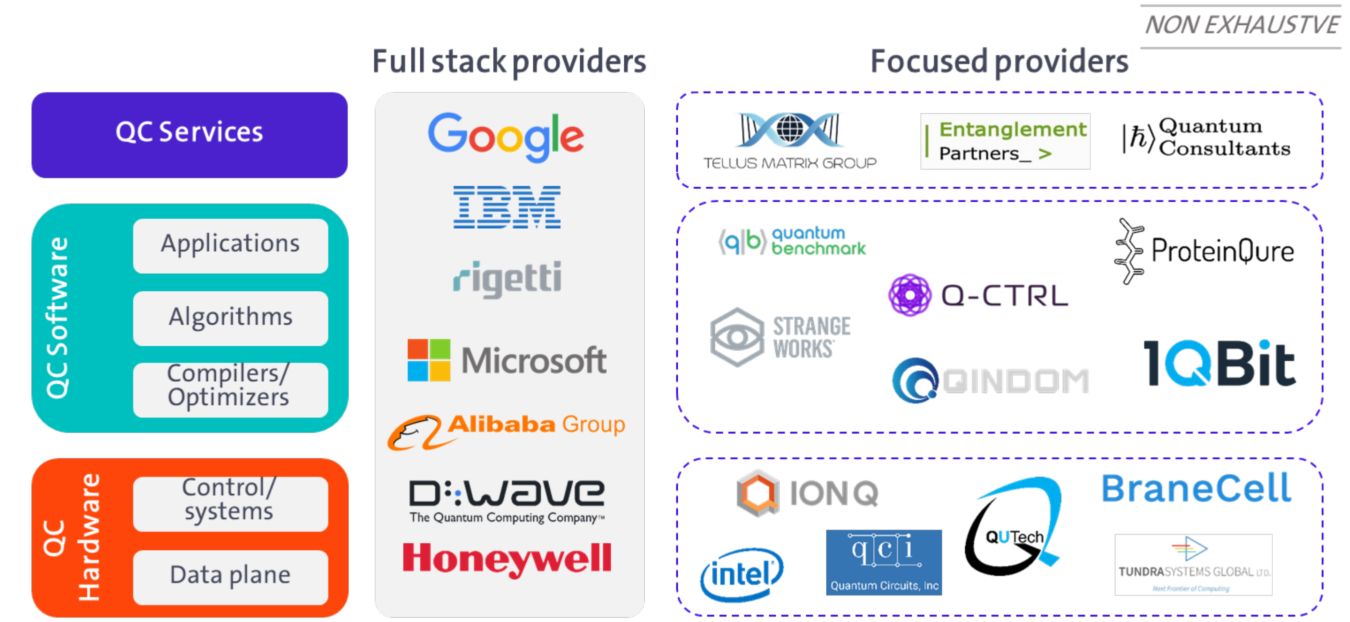
Effective QC investment strategies should consider how the efforts of government, academia and private sector are coordinated. Successful countries across the globe are therefore considering three main levers when defining QC policy:

- Development of QC science
- Creating a QC-qualified workforce
- Engaging with industry around QC technology

[10] "The quantum gold rush", Nature Magazine, October 2019

4.1 Developing QC science

As in traditional computing, the QC stack consists of three building blocks – hardware, software and services. Universities and private companies across the globe have adopted different approaches to QC science development, ranging from a "full stack" approach to specializing in specific areas. (See Figure 7.)



Source: quantumcomputingreport.com, Arthur D. Little analysis

Figure 7: Quantum computing stack

At the base of the QC stack, the data plane is the "heart" of a quantum computer, made up of arrays of entangled qubits and the structures needed to hold them in their places. Right above this is the systems control layer, which regulates the data plane and enables it to carry out operations. Hardware is currently the bottleneck in the development of QC solutions, given the intricacies of these machines, which, for example, must be housed at near-absolute-zero temperatures to prevent them from overheating. Moving onto the software layer, compilers/optimizers map the QC programming languages used for algorithms and applications onto the quantum hardware. Currently, QC software is deeply intertwined with its underlying hardware. However, like with traditional computing, as the technology evolves, software will become increasingly abstracted from specific hardware implementations. Additionally, convergence is expected between the different QC native languages and programming techniques. Above, there is a layer of services and tools which allow QC to solve real-life problems.

As of 2019, there are over 100 academic groups and government-affiliated research teams involved in the various aspects of QC hardware – each with their own features and designs[11]. Promising models currently being explored include superconducting systems, ion traps, nitrogen vacancy, quantum dots and topological qubits. This "custom-made" approach will continue until 2024[12], when a standard architecture is expected to emerge. Currently, QC infrastructure is very fragile, as the smallest vibrations, temperature fluctuations, electromagnetic waves, and other interactions with the outside environment may ultimately destroy the computer's quantum properties. This makes the operation and maintenance of quantum hardware and software complex and costly. For this reason, quantum computers are likely to live in dedicated facilities and be accessed as a service via the cloud from classical computers. Quantum computing-as-a-service (QCaaS) beta platforms are becoming an ideal alternative for businesses and universities, allowing them to leverage QC infrastructure capabilities without having to make significant investments to create, maintain or operate quantum computers. Companies such as D-Wave, IBM and, recently, Rigetti[13] are offering beta QCaaS cloud platforms, and it is expected that all other players will follow suit. Moreover, as recently announced by Linköping University[14], a quantum simulation logic system can be deployed over a classical supercomputer. This enables organizations to test some QC algorithms and develop related skills – again, avoiding the need to build, operate and maintain QC hardware.

[11] "Quantum Computing: Progress and Prospects", National Academy of Sciences, 2019
[12] "Strategy Guide to Navigating the Quantum Computing Hype", Gartner, September 2019
[13] "Rigetti launches the public beta of its Quantum Cloud Services", Tech Crunch, January 2019
[14] "Spreading light over quantum computers", Liköping University, September 2019

Given QC's emergence and the major benefits it promises, governments across the world are taking active roles in developing it. The US and others have created national QC coordination bodies, identifying and prioritizing fundamental scientific or technology problems whose solutions will have major economic and scientific impact. Other countries, such as Singapore and the UK, are promoting government-funded core research programs with different approaches, ranging from distributing small grants to funding projects that support long-term QC research. Meanwhile, China is fostering academic dialogue and collaboration between quantum-focused researchers across scientific disciplines and institutions, engaging the broader scientific community to highlight and share relevant benefits. (See Figure 8).

	Policy measures	Examples
1	Establish a **formal national QC coordination body**	**USA:** creation of the National Science and Technology Council Subcommittee on Quantum Information Science (SCQIS), to define QC policy roadmap and coordinate government funded R&D in quantum technologies
2	Strengthen **government-funded core research programs**	**Singapore:** A*Star (The Agency for Science, Technology, and Research) is a Singapore government agency and the Institute of Materials Research and Engineering (IMRE) is responsible for QC R&D **UK:** UKRI (UK Research and Innovation) provides grants to specific quantum computing research labs
3	Foster academic **dialogue and collaboration** between quantum-focused researchers across scientific disciplines and institutions	**China:** BAQIS is a newly formed research institution sponsored by the Beijing municipal government, with the partnership of leading research institutions including the Chinese Academy of Sciences, Peking University and Tsinghua University

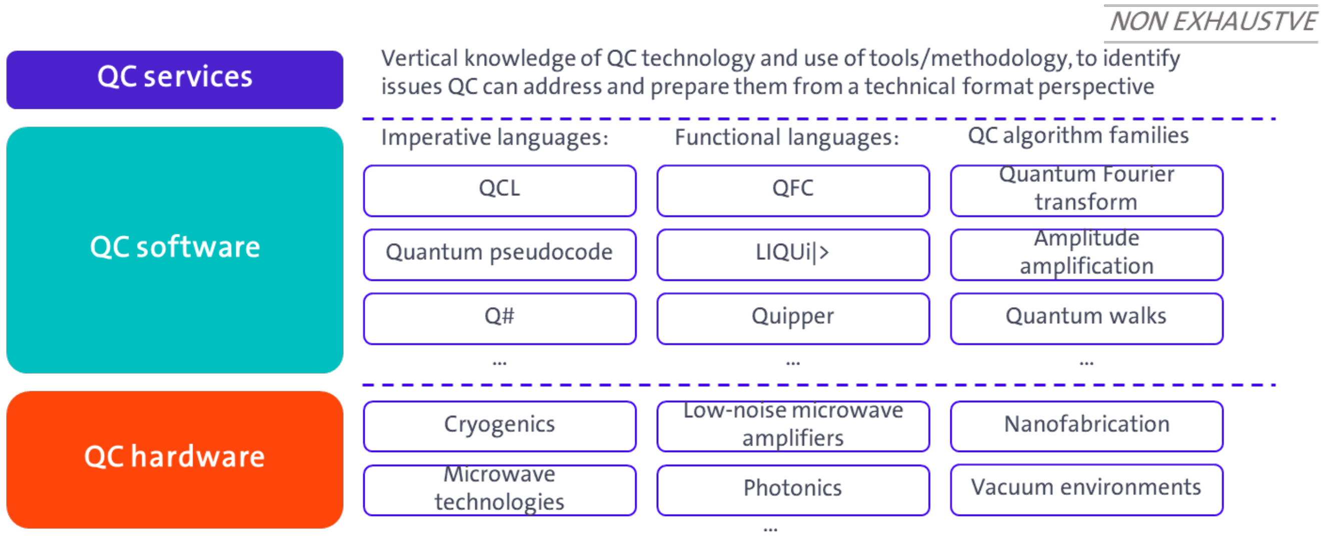
Source: Arthur D. Little analysis

Figure 8: Selected national policies to develop QC science

4.2 Creating a QC-qualified workforce

QC success is also creating a race for talent development and acquisition. The qualified labor pool with relevant experience is still very small, and experience is increasingly hard to obtain. By some accounts, fewer than 1,000 people in the world can claim to be doing advanced research in the field[15]. At the same time, QC must be understood not as an isolated science, but as a confluence of many scientific fields, ranging from dealing with cryogenic temperatures to creating QC-specific programming languages.

A competitive QC industry will need cross-discipline profiles with expertise in a range of physical, mathematical, computer science, information and engineering fields. (See Figure 9.) However, while new skills will be essential to addressing QC-specific problems, companies will still need traditional computing and associated skills, given both technologies will coexist and need to be integrated.



Source: quantumcomputingreport.com, Arthur D. Little analysis

Figure 9: Main skills by QC stack building block

[15] "The Next Talent Shortage: Quantum Computing Researchers" – The New York Times, 2018

Globally, policy makers are implementing various measures to ensure the development of QC skills, combining efforts from academia and the corporate world (see Figure 10). QC is gaining relevance and becoming an independent discipline at universities, driving the need for new faculty, programs, and initiatives at all levels. Private companies and academia are partnering to track and estimate the current and future workforce needs of the quantum industry, and ensure these needs are included in academic curriculums. Countries such as Singapore are looking to attract of foreign talent for QC technological roles by reducing red tape. This happens at a time when leading QC markets such as the US and EU are facing talent acquisition challenges given stricter immigration policies.

	Policy measures	Examples
1	Consider **quantum science and engineering as its own discipline**	Number of universities with active QC research groups by region[1]: Europe: +30; Americas: +50; APAC: +25; MEA: +5 
2	**Track and estimate** the **current and future workforce needs** of the quantum industry	**USA:** partnership between Microsoft and the University of Washington to promote and develop quantum knowledge and skills
3	Promote and facilitate attracting **foreign talent**, through special visa programs, tax incentives, etc.	**Singapore**: launch of Tech@SG program, making it easier for tech firms to hire foreign talent

Source: Arthur D. Little analysis
Notes: (1) Estimates based on quantumcomputingreport.com as of November 2019

Figure 10: Selected national policies to develop QC talent

4.3 Engaging with industry around QC technology

The potential of QC will only be fully unleashed when mainstream commercial QC applications are available to businesses. While maturity will vary from sector to sector, industry leaders should work closely with academic and government entities to make the most of QC when the technology is ready for specific use cases. Different initiatives are being undertaken to accelerate QC adoption within key industry verticals:

- In the US, a national consortium with participants from industry, academia and the government has been created to forecast and establish consensus on needs and roadblocks, coordinate efforts in pre-competitive research, address IP concerns and streamline technology-transfer mechanisms.
- Japan is promoting joint quantum technology research centers between industry leaders and academia, to accelerate pre-competitive quantum research and development.
- France is launching campaigns to drive awareness of how the QC revolution may impact its economy and different industries, as well as looking to nurture the adoption of quantum technologies. (See Figure 11.)

	Policy measures	Examples
1	Foster the formation of a **national consortium** with participants from industry, academia, and the government	**USA:** The US Quantum Economic Development Consortium (QED-C) has been set up to pull together industry, academics and other relevant researchers to help the US secure national pre-eminence in quantum computing
2	Promote **joint quantum technology research centers**	**Japan:** Agreement between IBM, Keio University and Industry leaders such as JSR, MUFG Bank, Mizuho Financial Group and Mitsubishi Chemical to accelerate Quantum Computing in the country
3	Maintain **awareness** of how the quantum revolution may impact the economy and the different industries, and how to nurture the adoption of quantum technologies	**France:** Launch of the Paris Center for Quantum Computing (PCQC) to promote, among other things, international visibility of quantum research in Paris and throughout France, dissemination of quantum research via workshops/visits and student exchanges, and collaboration with industry on commercialization of end-to-end quantum solutions

Source: Arthur D. Little analysis

Figure 11: Selected national policies for industry engagement

5 Policy options for KSA

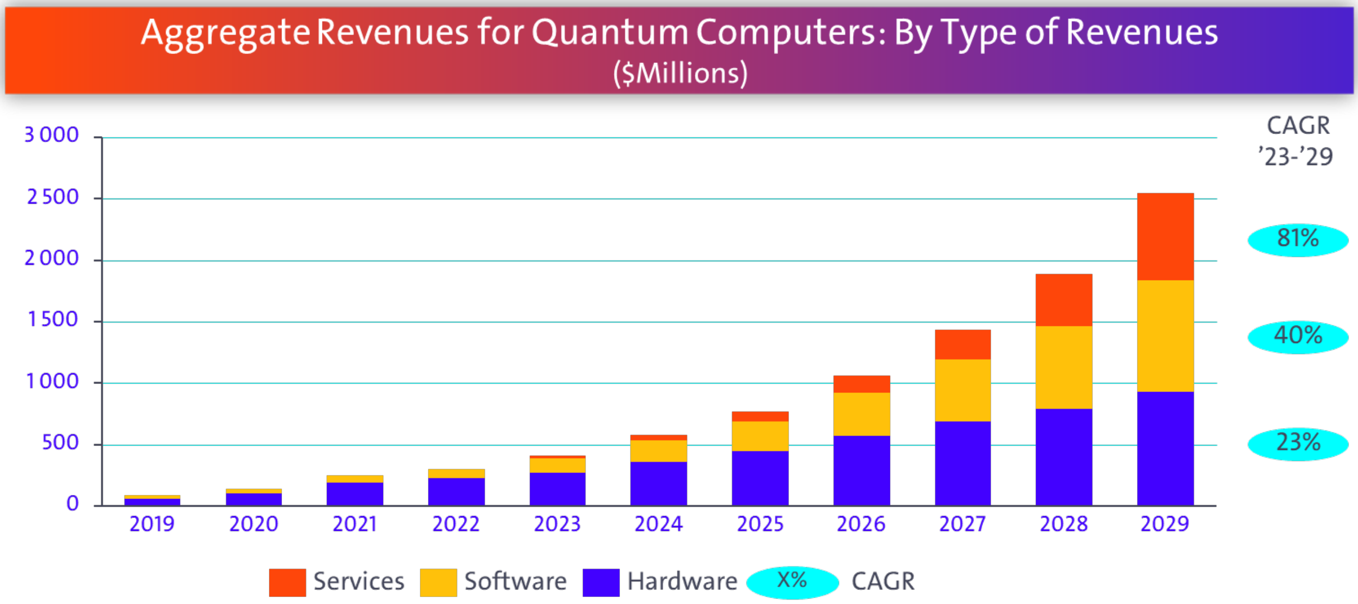
The speed at which QC technology is evolving, government support in advanced economies, and the opportunities and threats of quantum computing make it imperative for KSA to develop its own QC policy.

Full-fledged strategies, which are followed by countries such as the US and China, cover initiatives across the entire QC stack. Both countries have the financial muscle to back QC R&D with billions of dollars and are also supported in their efforts by national technology champions such as Alibaba, Microsoft and IBM. A large part of these investments is currently focused on the hardware building block, which, as previously mentioned, is highly capital intensive and still far from achieving technological convergence. This makes it riskier to invest in one specific technology. For this reason, a "lean QC approach" is being adopted by countries such as Singapore, focusing on developing QC capabilities and algorithms rather than heavily investing in QC hardware.

KSA's strategy should be driven by the specific growth opportunities it wishes to pursue and the resources it wants to commit to this endeavor. However, to qualify KSA for a relevant role in the QC race, the following lean approach policy actions should be undertaken to ensure the country is able to develop the necessary skills and capabilities in the mid-term:

5.1 Promote QC software and services

KSA can optimize investment and achieve a more relevant competitive advantage by focusing on developing software and services that support the interests of its national companies. This should be achieved through a government-funding program for both university and private sector R&D projects. The hardware layer can be either sourced as a service (QCaaS) or, for some algorithms, replaced by a quantum simulation logic system deployed on top of a supercomputer. This enables KSA to address the QC software and services market, which will see the largest growth in the next few years. (See Figure 12).



Source: Inside Quantum Technology 2019, Arthur D. Little analysis

Figure 12: Aggregate revenues for quantum computers by type of revenues (USD millions)

5.2 Establish a quantum computing council for Saudi Arabia

In order to ensure that KSA takes full advantage of the QC wave, the country should define a formal QC coordination body. As well as public entities such as MCIT, this should include academic institutions such as KAUST and industry leaders. Additionally, this project should be coordinated with existing initiatives such as King Abdulaziz City for Science and Technology (KACST). The scope of such council should cover the following tasks:

- Oversee QC initiatives in order to identify synergies.
- Identify R&D and business opportunities, ensuring enough funding is provided for relevant initiatives (for example, academic R&D projects, start-ups).
- Promote collaboration between academic institutions and the private sector.
- Maintain awareness of how the quantum revolution may impact the economy and sectors within it.

5.3 Invest in QC talent

In order to accelerate the development of a QC-qualified workforce, 3 key levers have been identified for KSA, ranging from initiatives in-house or abroad:

- Encourage the creation of specific QC disciplines in universities, with their own faculty and programs. Leading universities such as KAUST, which already possesses centers including the Shaheen Supercomputing Laboratory, could create a specific QC institute. This would provide a place where related fields could converge and contribute to the development of the science. Moreover, KSA should encourage the development of QC programming skills at both academic and professional levels to reap all the benefits of QC.
- Take advantage of visa restrictions in other markets and reduce red tape to attract professionals in QC and related fields for KSA's leading universities and companies. This measure is aligned with KSA's recent national policies around attracting top scientific and technological talent.
- Study alternatives such as sponsoring QC R&D lab initiatives abroad. For example, Japanese telco NTT data has recently established a QC research center in Silicon Valley, and Harbour. Space University in Barcelona, which offers courses of QC cryptography, is sponsored by the Moscow Institute of Technology.

5.4 Develop industrial use cases in collaboration with technology leaders

KSA can play a key role in engaging with industry leaders to develop use cases through partnerships with technology companies – the chosen model for most commercial activity in the field to date. Collaborations in place in other parts of the world include Volkswagen's and Google's work to develop batteries for electric vehicles, JP Morgan's and IBM's joint development of solutions related to risk assessment and portfolio optimization, and DEWA's alliance with Microsoft to develop energy optimization solutions. As part of the deal, DEWA will be able to program and test quantum algorithms on Microsoft's "Azure Quantum" platform, which can be deployed on classical infrastructure. This project will also give DEWA an easier migration to Microsoft's quantum computer once it is available.

Because it is immersed in an ambitious program to diversify its economy, and given QC's current scientific development, KSA is in a privileged position, from which it can combine the efforts of government institutions, academia and national leaders to prepare for the QC revolution. Moreover, given its size, industrial mix and regional influence, KSA seems very well positioned to have a relevant role in the wider Middle East. The options proposed above represent strategic initiatives that will allow KSA to "get in shape" in key areas, such as software and services, while leaving its options open until QC technology matures, especially around hardware. The opportunities for innovation across sectors, as well as QC's impact in cybersecurity, undoubtedly make quantum computing a marathon KSA should start training for now.

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Dr. Kevin Cullen, Vice President of Innovation and Economic Development at King Abdullah University of Science and Technology (KAUST)

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Abbreviations

AI – Artificial Intelligence

APAC – Asia Pacific

DEWA – Dubai Electricity and Water Authority

EU – European Union

IP – Intellectual Property

KAUST – King Abdullah University of Science and Technology

KSA – Kingdom of Saudi Arabia

MEA – Middle East and Africa

MCIT – Ministry of Communications and Information Technology

ML – Machine Learning

QC – Quantum Computing

QCL – Quantum Computation Language

QFC – Quantum Flow Charts

R&D – Research and Development

ROW– Rest of the World

USA – United States of America

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