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Swissnex Network in Asia and Australia

Regional Report 2022

The state of quantum technologies in the APAC region

Views from Asia and Australia

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Preamble

We are in the midst of a second quantum revolution. The first quantum revolution gave us new rules that govern physical reality. The second quantum revolution will take these rules and use them to develop new technologies[1].

In October 1900, a revolution in physics began unnoticed. On this day, Max Planck presented a new radiation law, which described the energy distribution of thermal radiation. Later it became clear that this law was incompatible with classical physics and required a revolution in the understanding of radiation and energy, i.e. that radiation consists of energy packets, the quanta. His work helped lay the foundation for quantum physics[2].

Following theoretical work by Paul Benioff, Richard Feynmann proposed building quantum computers to simulate quantum systems in 1981. Quantum computers are a reality today. In 1998 researchers at the Los Alamos National Laboratory, the Massachusetts Institute of Technology, and the University of California at Berkeley created the first quantum computer (2-qubit) that could be loaded with data and output a solution. Although the system was coherent for only a few nanoseconds and not very useful in solving meaningful problems, it demonstrated the principles of quantum computation. IBM has recently announced that it has created the world's largest quantum computer with 433 qubits, which would have the potential to run complex quantum computations well beyond the computational capability of any classical computer[3].

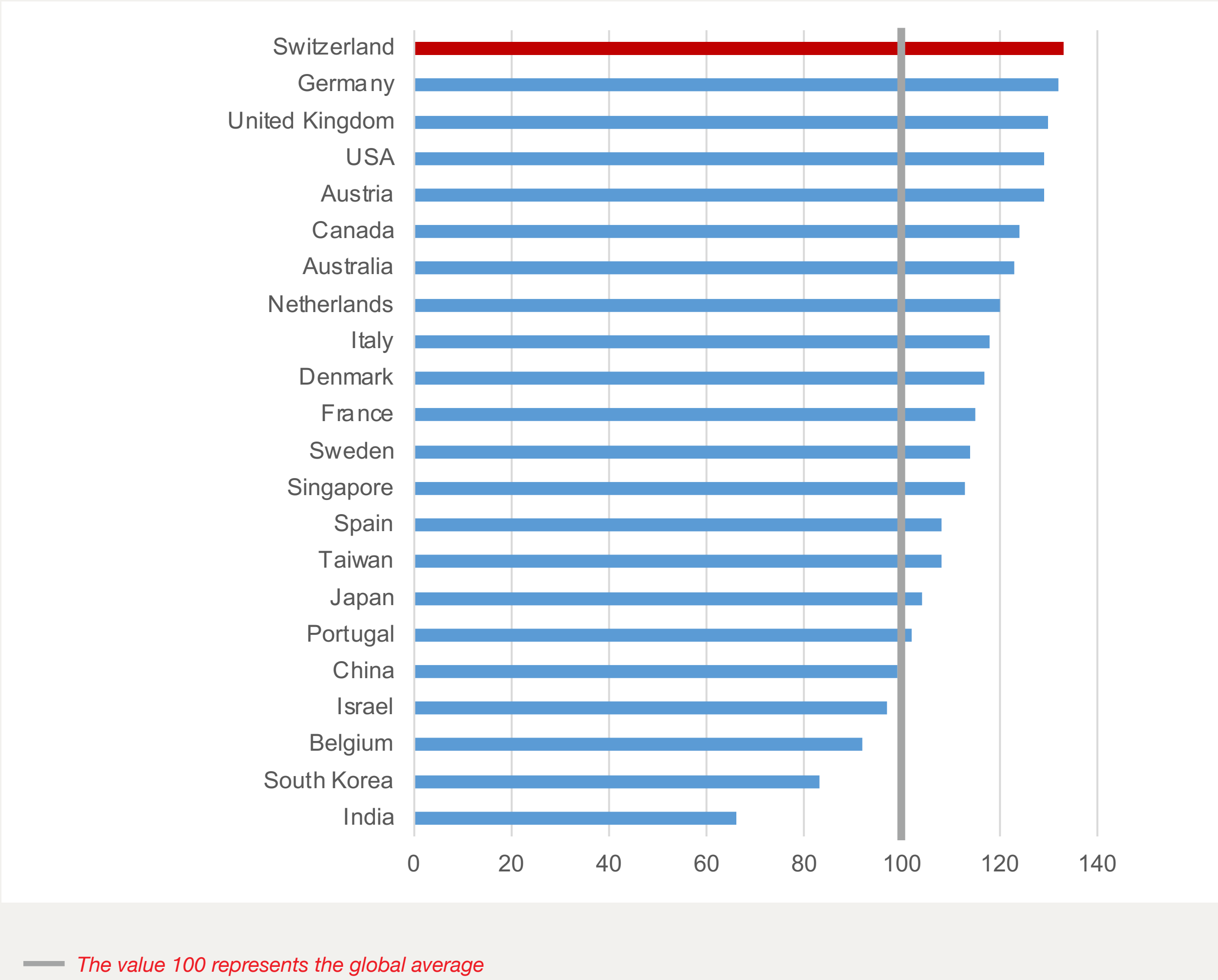
Quantum physics has led to many areas of research. Quantum computing, harnesses the laws of quantum mechanics to solve problems too complex for classical computers[4]. Quantum communication is a field of applied quantum physics closely related to quantum information processing and quantum teleportation[5]. Quantum sensing improves the accuracy of how we measure, navigate, study, explore, see, and interact with the world around us by sensing changes in motion, and electric and magnetic fields[6].

Quantum is a strategic area for all advanced economies in the world, as it can deliver solutions for almost all aspects of our daily lives, whether it be in agriculture, healthcare, financial services, manufacturing, communications, energy, etc. However, it can also an area where, because of the dual-use nature of some of the products that are being developed using quantum technologies, such as cryptography, it may quickly become a topic for national security. Quantum information technologies will almost certainly have significant impacts on national security—touching everything from extremely secure communications to faster code breaking to better detection of aircraft and submarines[7].

Switzerland has promoted quantum technologies from a very early stage with its cutting-edge research, excellent infrastructure and many innovative SMEs. Swiss researchers in this field have obtained more than 30 highly prestigious grants from the European Research Council[8] and the impact of publications by Swiss researchers measures 133% of the global average[9], ahead of Germany and the United Kingdom (Graph 1). Switzerland is also home to many successful quantum companies[10].

However, other countries have caught up, and in the case of some, they invest much more funds in R&D activities in the field of quantum computers than Switzerland. The discontinuation of Swiss participation in Horizon Europe, the European research framework programme, has made it more difficult for Swiss researchers to participate in international projects. It is only within the framework of international collaborations that it will be possible for Switzerland to remain competitive in this field in the future.[11].

[1] https://arxiv.org/ftp/quant-ph/papers/0206/0206091.pdf
[2] https://www.snexplores.org/article/explainer-quantum-world-super-small
[3] https://newsroom.ibm.com/2022-11-09-IBM-Unveils-400-Qubit-Plus-Quantum-Processor-and-Next-Generation-IBM-Quantum-System-Two
[4] https://www.ibm.com/topics/quantum-computing
[5] https://www.picoquant.com/applications/category/quantum-optics/quantum-communication
[6] https://www.baesystems.com/en-us/definition/what-is-quantum-sensing
[7] https://www2.deloitte.com/us/en/insights/industry/public-sector/the-impact-of-quantum-technology-on-national-security.html
[8] https://www.swiss-quantum.ch/SwissQuantum.pdf
[9] https://www.sbfi.admin.ch/sbfi/de/home/dienstleistungen/publikationen/publikationsdatenbank/s-n-2022-4/s-n-2022-4h.html
[10] https://qt.eu/about-quantum-flagship/the-european-community/directories/?q=&countries%5B%5D=switzerland
[11] Forschungslandschaft Schweiz: Ein technologisches Panorama
https://www.satw.ch/fileadmin/user_upload/SATW_Forschungslandschaft_Schweiz_SBFI-Studie_Lang_2022_DE.pdf



Graph 1: Indicator of impact of global quantum publications in the world 2016-2020 (Top 20 and others in the APAC region)

Switzerland has recently signed a Joint Statement on Cooperation in Quantum Information Science and Technology with the United States[12] and a Memorandum of Understanding with the UK, which includes quantum technology as one of the focus areas[13].

In Australia and in the countries where the Swissnex network is present in Asia (China, India, Japan, Korea and Singapore) considerable efforts have been put into quantum research and technologies and they are set to reap the benefits of their investments in the coming years. Together they have produced over a third of research papers globally in quantum in the period 2016-2020. However, none of these countries (other than China at #7 and Japan at #9) figure amongst Switzerland's top 10 partner countries as far as research publications in quantum is concerned[14].

[12] https://www.eda.admin.ch/countries/usa/en/home/news/news.html/content/countries/usa/en/meta/news/embassy/2022/October swiss-us-quantum-agreement
[13] https://www.eda.admin.ch/europa/en/home/aktuell/medienmitteilungen.html/content/europa/en/meta/news/2022/11/10/91369
[14] Scientific publications in Switzerland, 2008–2020 A bibliometric analysis of scientific research in Switzerland https://www.sbfi.admin.ch/sbfi/en/home/services/publications/data-base-publications/publications-08-20.html

This report provides an overview in the development of quantum computing and technologies in the APAC region, through the Swissnex locations (Australia, China, India, Japan, Korea and Singapore). A summary, followed by a report on each of the countries is given. We aim to showcase excellence in quantum research and technologies in Asia and Australia, with the objective of nurturing the possibility of establishing research cooperation between Switzerland and these countries.

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Summary

The policy agenda for quantum

Major economies in Asia and Australia have adopted quantum technologies as the pathway to future prosperity.

Australia

Australia identified quantum as one of the top five "emerging technologies" in its Digital Economy Strategy and as one of its nine "strategic priority technology areas" in its Action Plan for Critical Technologies.

China

China's 14th Five-Year Plan (2021-2025) listed quantum as a strategic technological industry and advances in the field are defined as a priority in the 2015 "Made in China 2025" Plan.

India

In India, quantum technologies has been identified as one of 9 technology frontiers identified by the Prime Minister's Science, Technology and Innovation Advisory Council with substantial funding being committed.

Japan

Japan places quantum technology on the top of the list of focus areas for investments under the Prime Minister's initiative, New Form of Capitalism, along with AI, biotechnology, digital and decarbonization. In its Innovation Strategy 2022, it targets a market of 10 million users for quantum technology in Japan by 2030, with a production scale of 50 trillion yen.

South Korea

South Kora announced a roadmap for quantum technologies in 2021.

Singapore

Singapore has identified Quantum technologies as a "key research area" and as a "core digital capability" in its five year plan for research and development called RIE2025.

Funding

It is no surprise that the Government is the principal funder of research and development in quantum technologies at this time.

Australia

Australia has funded two quantum-focused "Centres of Excellence", with a total investment of AU$ 65.6 Million (CHF 40.58 million approx.). Estimates put Government funding into quantum research at close to AUD 300 million since 1999 (CHF 185.6 million approx.). An AU$ 1 billion (CHF 617.8 million approx.) "Critical Technology Fund" has also been set up to support home-grown innovation and manufacturing, in areas which include quantum, and AU$ 4 million (CHF 2.47 million approx.) for up to 20 PhDs in quantum research.

China

China has announced public funding of CHF 13 billion for quantum technology in the period 2021-2025. It is estimated that in total at least CHF 24 billion have been invested by the Chinese government into quantum technology since the mid-1980s. Taiwan intends to invest NT$8 billion (CHF 251.76 million) into the establishment of a research and development platform on quantum technologies by 2026.

India

In India, after an initial investment of INR 80 crores (CHF 8.97 million approx.) in 2019, India's Finance Minister committed a sum of INR 8000 crores (CHF 897 million approx.) over a period five years, for the National Mission on Quantum Technologies and Applications (NM-QTA) in 2020.

Japan

Japan has allocated a sum of 79 billion yen (CHF 551 million approx.) for the current fiscal year. The focus is on industry-academia collaboration and public-private partnerships and includes programs such as the Moonshot R&D Program Goal 6, Realization of a fault-tolerant universal quantum computer, Cross-ministerial Strategic innovation Promotion Program (SIP), Photonics and Quantum Technology for Society 5.0, Public / Private R&D Investment Strategic Expansion Program (PRISM), Quantum integration innovation area and the Quantum Leap Flagship Program (Q-LEAP).

South Korea

In 2019, South Korea announced the investment of US$ 40 million (CHF 37 million approx.) in quantum computing over the following five years to develop core quantum technologies, followed by additional investment of US$ 11.9 million (CHF 11 million approx.) regarded the next-generation ICT technology.

Singapore

Singapore had started funding quantum technologies as early as 2002 and has since then continuously expanded its efforts naming Quantum Technologies as a "key research area" with more than SG$ 300 million (CHF 205 million approx.) invested, including SG$ 170 million (CHF 116 million approx.) in the last 5 years.

Main Actors

While the primary actors in the quantum space are still the Government and public institutions, an ecosystem, which also includes start-ups and private entities, is developing in the region.

Australia

There are now at least 22 quantum-related research institutions in Australia. Momentum is growing in Australia across government, industry, and academia to capitalise and build on decades of research and capacity building in quantum. Industry is increasingly investing in the quantum sector in Australia. Estimates put the combined cumulative funding into 17 active Australian quantum companies at over AU$ 400 million.

China

Public institutions play a key role in quantum research in China, most importantly the Chinese Academy of Sciences, the Ministry of Science and Technology, the Ministry of Industry and Information Technology and the National Natural Science Foundation. Additionally, municipal governments such as Beijing, major public banks and funds are involved. Private sector is more involved in quantum computing. The National University of Technology and Defense (NUDT) and the People's Liberation Army (PLA) have a big interest in quantum. Most important tech giants in China have established their own quantum research initiatives. Quantum start-ups are emerging with the support of the government.

India

Government entities, such as the Department of Science and Technology, the Indian Space Research Organisation, the Office of the Principal Scientific Adviser to the Government of India, the Department of Atomic Energy, the Defence Research and Development Organisation and the Ministry of Electronics and Information Technology are all involved in India's quantum story. It is estimated that some 40 to 50 research groups in academia are involved in quantum research in India, and some 15 to 20 start-ups are also active. Some 15 to 20 Indian IT service providers are building quantum based applications and solutions. A non-profit entity brings industry, academia and the Government together on a common platform.

Japan

Leading universities, as well as industry giants are heavily invested in Japan's quantum efforts. In addition, there is a strong push for strong start-ups and unicorns are sought in this field. Currently, the majority of the more than dozen quantum technology related start-ups are working on software development. These include QunaSys Inc., JiJ Inc., Fixstars Corp., bleuquat, Quemix, Groovenauts, Nextremer and ABEJA. Then there are R&D and consulting firms like Sigma Eye and a smaller but growing number hardware providers, e.g. QuEL Inc. and Nanofiber Quantum Technologies.

South Korea

The Korean Government aims to foster 33 quantum computing research groups including 7 key teams for core technology of quantum computing and 26 teams for promising technologies. According to the Korean strategy, the research community will provide the bridge to industrial use of quantum.

Singapore

In Singapore, the National Research Foundation (NRF), which sets the national direction for research and development since 2006, established the Centre for Quantum Technologies (CQT) as the first research centre of excellence in 2007. Hosted by the National University of Singapore, CQT has grown to be the linchpin of Singapore's quantum research base, that has already produced 2 spin-offs and 4 startups. The government coordinates its quantum strategy via the National Quantum Office and encourages the commercialization of its quantum capabilities with the Quantum Engineering Programme.

Main areas of research

Research in all fields related to quantum technologies are being carried out in Asia and in Australia. These include quantum computing, quantum communications, quantum sensors and quantum materials. Research leading to potential dual use applications is also being undertaken.

Australia

Australia has one of the world's most advanced, capabilities in silicon-based computers. Research capabilities in quantum sensing, quantum communications, and so-called enabling technologies, cover the breadth of the quantum research ecosystem in Australia.

China

In China, the main areas of research in quantum technologies include quantum communication, quantum computing (China is one of the most advanced countries in photonic processors), quantum sensing and metrology. China also invests in quantum software, e.g on optical quantum computing algorithms

India

The vertical focus areas, which have been prioritised in India's National Mission on Quantum Technologies and Applications include quantum clocks, quantum sensors, quantum imaging, quantum computing and quantum communications. The Mission aims to develop trained manpower for the quantum industry. Fields of research for the academic sector include quantum technology development, quantum game theory, quantum secure communication, quantum random number generation, quantum sensing and metrology, quantum phenomena in superconducting circuits, quantum optics, quantum information processing. In addition, algorithms for cryptography and machine learning and applications in quantum key distribution, quantum dense coding, quantum teleportation, quantum cryptography are also being developed.

Japan

Japan has strong presence in all fields of the spectrum. The ten national research hubs are set up for quantum computing, quantum sensing, quantum materials, quantum computer applications, quantum life science, quantum security, quantum device and quantum solutions. Fujitsu is set to launch its first superconducting quantum computers in FY 2023. Toshiba has a world's first commercial trial of quantum secured communication service with the BT Group in the UK.

South Korea

In South Korea, quantum computing including algorithms; error correction applications, hardware and processors; quantum communications, which includes quantum cryptography and communication technology, international standardization and expanding coverage of wireless cryptography communications; and research in quantum sensors to expedite commercialization are the key focus areas. South Korea also intends to train about 1,000 researchers and scientists in the quantum space by 2030.

Singapore

In Singapore, the focus for research in quantum computing and processors is to build capabilities ranging from hardware to middleware leading to applications of quantum computing. In quantum communication and security: The National Quantum-Safe Network is a nationwide platform and a field-deployed testbed for a systematic construction of quantum-safe communication technologies. The National Quantum Fabless Foundry: Developing quantum devices that require micro and nano fabrications and build home-grown quantum production and eventually quantum computers.

Successes in quantum technologies

Some countries covered in this report have started their quantum journey quite some time ago, while other are just starting theirs. However, all of them have already achieved successes.

Australia

Earlier this year, Silicon Quantum Computing, an Australian quantum computing company announced the world's first quantum integrated circuit manufactured at the atomic scale.

China

In China, a secure communication line between Beijing and Shanghai, finalised in 2016 and its expansion, complemented by the Mozi satellite, now covers a distance of more than 2000 km. It has the ambition of reaching 35,000 km over time.

India

Scientists from India have demonstrated the ability, albeit over short distances, the capacity of transmitting texts, images and two-way video calling. A laboratory has demonstrated a quantum state estimation tool to understand properties of different types of light with a very high accuracy.

Japan

Japan's first domestic commercial supercomputers is set to come to the market in FY 2023. BT Group in UK and Toshiba Corp. have launched the world's first commercial trial of quantum secured communication services in April 2022. Quantum sensor applications in Magnetic Resonance Imaging (MRI), electric vehicle battery monitoring, life sciences and more are being developed. Japan's Coax, is the sole global manufacturer of superconducting cables suitable for quantum computers and NF Holdings is the only major provider of low noise power supplies. Connectors also mainly come from Japan.

South Korea

In South Korea, quantum computing - including algorithms, error correction applications, hardware and processors; quantum communications - which includes quantum cryptography and communication technology, international standardization and expanding coverage of wireless cryptography communications; and research in quantum sensors - to expedite commercialization are the key focus areas. South Korea also intends to train about 1,000 researchers and scientists in the quantum space by 2030. The Swiss company ID Quantique (IDQ) and SK Telecoms installed the most advanced key management, configuration, and monitoring solution for safe information sharing among government bodies.

Singapore

The Centre for Quantum Technologies at the National University of Singapore had sent the first quantum Nano-Satellite, SpooQy-1, to space to demonstrate quantum entanglement in 2019[1].

[1] https://www.quantumlah.org/about/highlight/2020-06-spooqy-quantum-satellite

International Collaborations

With the exception of China, all the other countries covered in this report have extensive international cooperation agreements, amongst themselves, as globally.

Australia

Australia has many international collaborations, which include quantum policy dialogues, working groups and strategic projects for the development of critical technologies, including quantum. Countries involved in these collaborations include Canada, India, Japan, New Zealand, the United Kingdom, and the United States.

China

Quantum research in China has benefitted from international cooperation, as many of its experts have studied abroad and returned to China. However, international collaboration of Chinese quantum research groups is rare and declining. The US have already implemented sanctions against 28 quantum computing entities of China or with ties to China.

India

India has a few active international cooperation programmes in quantum research, which include setting up virtual centres on quantum computing and in photonics, creating dedicated research funds, collaboration on quantum communications and on high performance computing. The partner countries include Australia, Brazil, China, Finland, Israel, Russia, South Africa and the European Union.

Japan

Japan has been focusing its efforts to strengthen ties with the US and EU. In 2019, Japan signed the Tokyo Statement on Quantum Cooperation with the US, which was elevated two years later into an Implementation Agreement under the S&T Cooperation Agreement. Cooperation between the two countries are intensifying in light of the tension between the US and China. The EU is considered another strong partner, with the two sides agreeing on cooperation since 2018. As for industry players, the major presence of IBM, the global giant, can be highlighted. There are more collaborations such as those between Fujitsu and QuTech (Netherlands) and NEC and D-Wave (Canada).

South Korea

A quantum information cooperative research institute was established in the US as a follow-up measure to the South Korea-US presidential summit on May 2022. South Korea seeks close collaboration to help advance the quantum computing technology, through cross-sector cooperation at national and international level.

Singapore

Singapore looks to expand and maintain a network of international collaborations, to attract and develop talents from all over Asia and the world. These include e.g. national level Memoranda of Understandings with Finland. There are further Memoranda of Understandings with universities from India, Italy, Japan, New Zealand and Thailand.

Outlook for the future

All the countries include in this report have made big bets on quantum technologies and put in place the structures and funding requisite to achieve their goals.

Australia

Momentum is growing in Australia across government, industry, and academia to capitalise and build on decades of research and capacity building in quantum. However, some consider that the current level of investment is insufficient and risks losing its competitive edge, including through brain drain. To attract foreign talents, the Australian government has put in place privileged visa pathways for quantum scientists through a Global Business and Talent Attraction Taskforce.

China

China has made great achievements in the past years, but is mostly excelling in the applications of quantum research. Major breakthroughs in fundamental research are still missing. China will also take further steps to ensure national security, such as establishing a national standard for quantum cryptography. China fosters the talent development in quantum by establishing training programs for specialists, strengthening academic programs and including quantum education into the education plans.

India

Quantum technology is expected to reach critical maturity in India by 2026-27. It is estimated that its adoption across industries has the potential to add $310 billion to the Indian economy by 2030.

Japan

Japan plans on launching its first indigenously developed quantum computer by March 2024 and having 10 million people using the technology in the country by 2030. It aims to increase R&D, and production value by quantum technology to 50 trillion yen by 2030. Another goal is to create unicorn start-ups in this strategic field. The country is expected to accelerate its move to enhance ties with the US, EU and advanced countries such as Canada and the UK.

South Korea

Quantum technology is in a transitional stage in South Korea as global key players are pushing forward commercialization. Consequently, immediate demand for quantum will be mainly from research institutes. It is expected that the research community will provide the bridge to industrial use of quantum.

Singapore

Singapore encourages its researchers to commercialise their quantum capabilities, which has led to several spin-offs and start-ups. The Government plans to expand competence in quantum technologies in areas such as quantum communications and quantum key distribution, quantum sensing and imaging, as well as quantum algorithms.

Collaboration opportunities for Switzerland

The countries covered in this report see different ways in which they could collaborate with Switzerland.

Australia

For Australia, adding a quantum-focused component would enhance the existing bilateral cooperation with Switzerland.

China

Quantum research has become a geopolitical battlefield and cooperation between Switzerland and China in the field is delicate and needs to be well considered. In general, cooperation on the software side might be less critical, as would quantum sensing and metrology.

India

The Indian authorities seek collaboration with Switzerland in the areas of artificial intelligence and quantum science and technology, which would generate societal benefits. Moreover, a large IT services company has expressed interest in interaction with Swiss start-ups.

Japan

Japan is increasing its funding not only for its own quantum R&D but for researcher exchange in the strategic field. It is expected that there will be more opportunities for Swiss researchers to invite Japanese researchers or be invited to Japan at least for the next three years. Moreover, in light of geopolitical developments, Japan strongly seeks to work with like-minded countries. Switzerland is one of the countries that Japan welcomes enhanced collaboration.

South Korea

The complementarity between Switzerland and South Korea might pave the way to the translation of research outcomes - achieved by Swiss research organizations and agile small companies - into large scale commercial applications by South Korean industrial players.

Singapore

Singapore, due to its small population needs to attract talent and retain it. The focus of collaborations should thus be on deepening existing networks and build up a common talent pool. Many senior researchers in Singapore have studied in Swiss universities and have established non-formal research collaborations with Swiss researchers. These links could be used as entry points to establish programmes with the aim of joint talent development.

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Australia

Context

Earlier this year, Silicon Quantum Computing, a quantum computing company out of Sydney, announced the world's first quantum integrated circuit manufactured at the atomic scale[1]. This breakthrough received wide coverage from news outlet around the globe and marked another milestone for the company, less than a decade after it announced it had developed the world's first single-atom transistor. Anything but an accident, this success is a confirmation of the excellence in quantum research available in Australia and the emergence of top quantum companies working on various applications of quantum physics. With strong foundations in quantum optics research and first generation quantum technologies, Australia nurtured since the 1990s a dense network of research groups with targeted long-term funding instruments, such as the "Centres of Excellence" programme[2] of the Australian Research Council and various defence and industry grants[3]. The Australian government confirmed a National Quantum Advisory Committee, chaired by its Chief Scientist Dr Cathy Foley, to spearhead the development of its first Quantum Strategy in a push to coordinate Australia's quantum capability across research, industry and government[4].

Momentum is growing in Australia across government, industry, and academia to translate decades of research in quantum and capacity building into commercial applications.

State of quantum research in Australia

Funding, and funding sources. The Australian Research Council (ARC), historically, has provided most of the funding into quantum basic research in Australia. For the period 2017-2023, the ARC is funding two quantum-focused "Centres of Excellence" (COE). The COE for Quantum Computation and Communication Technology (CQC2T) will receive AUD 33.7 million[5] and the COE for Engineered Quantum Systems (EQUS) AUD 31.9 million[6], and they have both been funded since 2011. Another four active COE with significant quantum physics research focused on technology and applications operate with separate funding. Estimates put the ARC funding into quantum research at close to AUD 300 million since 1999[7].

In recent years, the focus of the Australian government has shifted to accommodate the pivot towards the commercialisation of quantum technologies. It identified quantum as one of the top five "emerging technologies" in its Digital Economy Strategy[8] and as one of its nine "strategic priority technology areas" in its Action Plan for Critical Technologies[9]. Building on recommendations issued

[1] Silicon Quantum Computing, "Silicon Quantum Computing announces the world's first integrated circuit manufactured at the atomic scale", June 2022, online
[2] Australian Research Council, "ARC Centres of Excellence", September 2022, online
[3] CSIRO, "Growing Australia's Quantum Technology Industry", May 2020, online
[4] Department of Industry and Science, "National Quantum Advisory Committee", September 2022, online
[5] Australian Research Council, Centre of Excellence for Quantum Computation and Communication Technology, 2017, online
[6] Australian Research Council, Centre of Excellence for Engineered Quantum Systems, 2017, online
[7] Australian Strategic Policy Institute, "An Australian strategy for the quantum revolution", May 2021, online
[8] Department of Prime Minister and Cabinet, "Digital Economy Strategy 2022", May 2022, online
[9] Department of Industry, Science and Resources, "Action Plan for Critical Technologies", November 2021, online

by the CSIRO's "Growing Australia's Quantum Technology Industry" roadmap, it allocated AUD 111 million in the 2021 budget, of which AUD 70 million will go to a Quantum Commercialisation Hub to foster strategic partnerships with likeminded countries and help Australian quantum companies access new markets and investors[10]. Most recently, the new Labor government confirmed the creation of a AUD 1 billion "Critical Technology Fund" to support home-grown innovation and manufacturing in, among other areas, quantum. It also announced an additional AUD 4 million for up to 20 PhDs in quantum research[11].

In addition to ARC-funded schemes and government initiatives, the industry is increasingly investing in the quantum sector in Australia. Estimates put the combined cumulative funding into 17 active Australian quantum companies at over AUD 400 million. Silicon Quantum Computing (SQC) is leading the pack with a AUD 130 million Series-A investment round[12].

Main actors, both public and private sectors

There are now at least 22 quantum-related research institutions across Australia conducting quantum physics[13] and a number of State-led initiatives. In Sydney for example, the four main universities[14] together with the New South Wales government have established the Sydney Quantum Academy with AUD 35 million in funding to foster collaboration, support industry engagement and entrepreneurship[15]. Sydney is also home to the ARC's COE for Quantum Computation and Communication Technology (CQC2T) headquartered at the University of New South Wales.

The concentration of quantum research groups and their spin-off companies, such as SQC, formerly a research group within CQC2T, has led large tech companies to invest in the ecosystem as well. Microsoft, for example, has established a presence in Sydney via its StationQ (now Microsoft Quantum) research team at the University of Sydney – also a member of the other quantum-focused ARC's COE for Engineered Quantum Systems (EQUS)[16]. IBM is involved in various research groups across Australia, and notably established its IBMQ Hub at the University of Melbourne to accelerate research in quantum computing[17].

Outlook for the coming years

Momentum is growing in Australia across government, industry, and academia to capitalise and build on decades of research and capacity building in quantum. Australia has been a pioneer in quantum technology development. However, various experts consider the current level of investment insufficient[18,19]. Australia is struggling to keep pace with the world leaders (CN, DE, FR, US, etc.) and risks losing its competitive edge, whether through brain drain or lack of political leadership in the Australian context where short electoral cycles can compromise ambitious long-term developments. To attract foreign talents, the government has put in place privileged visa pathways for quantum scientists through a Global Business and Talent Attraction Taskforce[20].

Main areas of research

Australia prides itself with superior, if not the world's most advanced, capabilities in silicon-based computers. Sustained funding into various long-term national research programmes and into the two active quantum-focused ARC's COE has resulted in a large research output in quantum computing. In addition, research capabilities in quantum sensing, quantum communications, and

[10] Department of Industry, Science and Resources, "$111 million investment to back Australia's quantum technology future", November 2021, online
[11] Department of Industry, Science and Resources, "Quantum breakthrough to fuel Australian Industry", June 2022, online
[12] Silicon Quantum Computing, "Silicon Quantum Computing launches $130m Series A capital raising", June 2022, online
[13] CSIRO, "Growing Australia's Quantum Technology Industry", May 2020, online
[14] University of Sydney, University of Technology Sydney, University of New South Wales, and Macquarie University
[15] Sydney Quantum Academy, September 2020, online
[16] University of Sydney, "Microsoft and University of Sydney forge quantum partnership", July 2017, online
[17] University of Melbourne, "University of Melbourne collaborates with IBM to accelerate quantum computing", December 2017, online
[18] Australian Strategic Policy Institute, "An Australian strategy for the quantum revolution", May 2021, online
[19] Australian institute of International Affairs, "Realising Australia's Quantum Potential", December 2021, online
[20] Australian Government, "Quantum science benefits from visa scheme", September 2022, online

so-called enabling technologies, cover the breadth of the quantum research ecosystem in Australia. Examples of leading Australian R&D companies that collaborate closely with universities in those areas include:

- Silicon Quantum Computing is developing silicon-based quantum computing technologies.
- Quantum Brilliance is using nitrogen-vacancy defects in diamond to develop quantum microprocessors which can operate at room temperature.
- QuintessenceLabs is developing quantum-enhanced cybersecurity technologies and a pioneer in quantum key distribution.
- Q-CTRL is developing advanced quantum control solutions to help solve quantum noise and decoherence challenges in quantum technologies.

International cooperation in quantum research

Australia and the United States signed a Joint Statement on Cooperation in Quantum Science and Technology in 2021[21]. This format will introduce a quantum policy dialogue between Australian and American senior officials, as well as working level meetings for the development of strategic projects. The signing of this agreement is part of a sustained effort to extend collaboration stemming from defence and security arrangements (Five Eyes, AUKUS, Quad) to strategic technological areas such as quantum, cyber security or artificial intelligence. The AUKUS trilateral partnership (AU, UK and US) includes an AUKUS Quantum Arrangement working group[22] while the Quad (AU, IN, JP and US) specifically identifies quantum in its working group on "critical and emerging technologies"[23]. Australia and India also nurtures a bilateral framework agreement for the development of critical technologies[24], including quantum, and the two countries set up a scholarship programme, the Cyber and Critical Technology Partnership[25].

Collaboration opportunities for Switzerland

The Swiss National Science Foundation supports financially more cooperation with Australia than with any other country outside Europe and North America – 956 projects since 2005 for a total budget well over AUD 100 million, and the Australian Research Council lists Switzerland as the 10th preferred partners for Australian researchers. This intensive collaboration led to the signing of a MoU on cooperation in science, research and innovation between Switzerland and Australia in 2013 and subsequent joint committee meetings. Adding a quantum-focused component would enhance the existing bilateral format.

The Swiss Government Excellence Scholarship and ThinkSwiss Research Scholarship both enable the mobility of young Australian researchers. Research groups in quantum-related fields in Switzerland should use both programmes to intensify their collaboration with Australia and initiate joint research projects. The strong linkages between Swiss and Australian universities, with over 150 agreements overseeing mobility and research collaboration, constitute the ideal springboard for Swiss researchers interested in plugging into the Australian quantum ecosystem.

[21] Department of Industry, Science and Resources, "Australia and United States partner to build quantum future", November 2021, online
[22] Department of Prime Minister and Cabinet, "Joint Leaders statement to mark one year of AUKUS", September 2022, online
[23] Department of Foreign Affairs and Trade, "Quad", September 2022, online
[24] Department of Foreign Affairs and Trade, "Partnerships and Agreements", September 2022, online
[25] Department of Foreign Affairs and Trade, "Australia-India Cyber and Critical Technology Partnership Grants", April 2022, online

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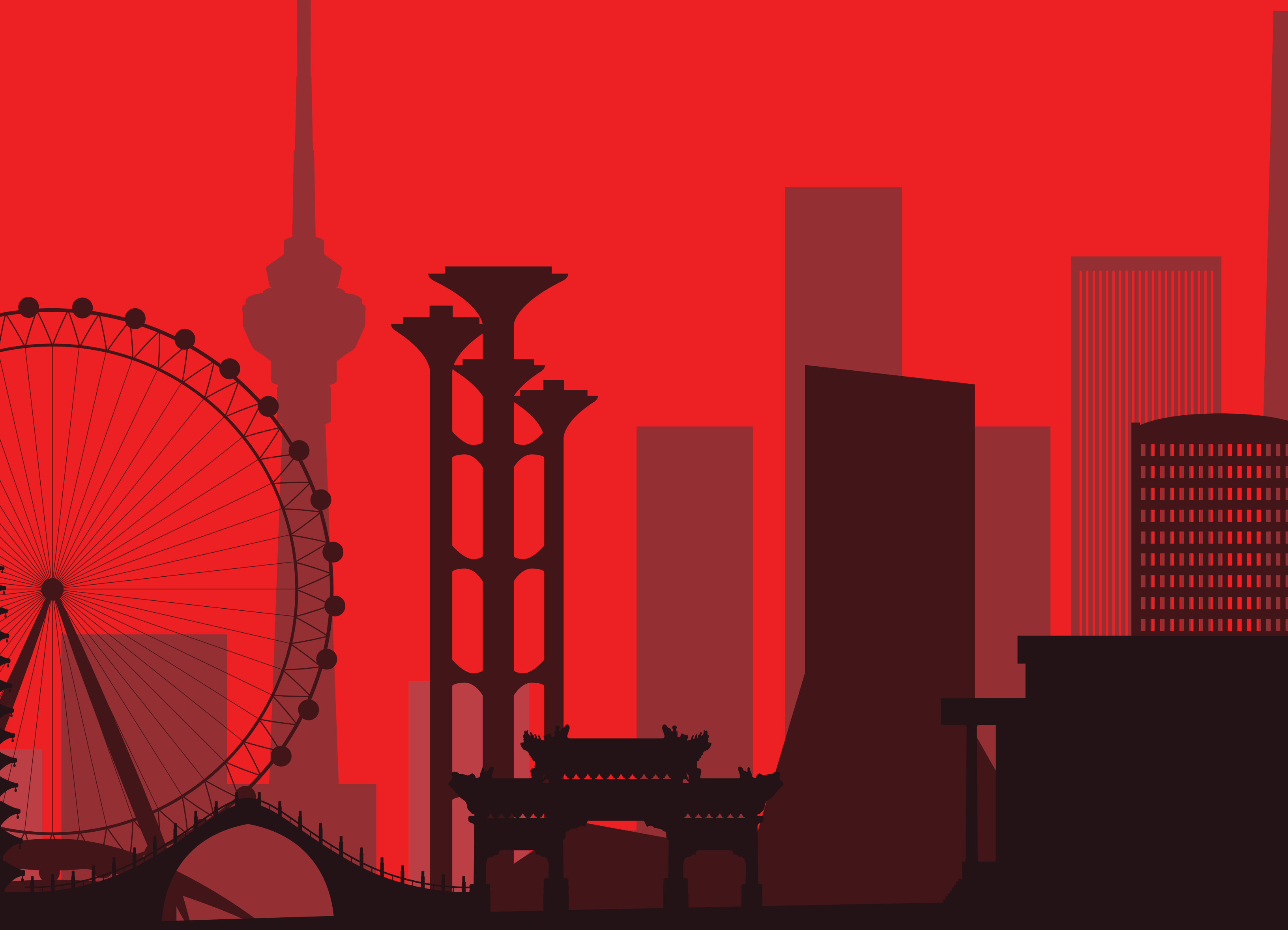

China

China

China is eager to become a worldwide leader in quantum technology. In its 14th Five-Year Plan (2021-2025)[1] quantum is listed as a strategic technological industry and advances in the field are defined as a priority in the new "Made in China 2025" Plan from 2015[2], an initiative with the goal to achieve international independence in key industry areas.

China is eager to become a worldwide leader in quantum technology. It currently produces 22% of all publications in the field and focuses heavily on quantum communication and computing.

State of quantum research

Between 2008 and 2020, China was the country with the highest output of publications in the area of quantum, responsible for 22.1% of the global output. However, looking at the relative citation index, a mean to measure the impact of publications, China is only on the 18th place of the ranking led by Switzerland, Germany and the US.[3] Interestingly, China holds more than 50% of all patents in quantum technologies, compared to about 11% of by the EU and 10% by the US.[4]

Funding, and funding sources

China is investing heavily into the field. Funding is mainly provided by the central and local governments, more specifically the Chinese Academy of Sciences (CAS) and the National Natural Science Foundation of China (NSFC). For the years 2021-2025 China had announced 13 billion CHF of public funding for quantum technology, more than double the investments of the EU (7 billion CHF) and four times more than the US (2.6 billion CHF).[5] It is estimated that in total at least 24 billion CHF have been invested by the Chinese government into quantum technology between mid-1980s-2022.[6] Additionally, big tech companies are investing considerable amounts of money into the field, mainly focusing on computing.

Main actors, both public and private sectors[7]

Public institutions play a key role in quantum research in China, most importantly the CAS, the Ministry of Science

[1] Translation of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035, Center for Security and Emerging Technology, https://cset.georgetown.edu/publication/china-14th-five-year-plan/
[2] Made in China 2025 Website, https://english.www.gov.cn/2016special/madeinchina2025/
[3] Wissenschaftliche Publikationen in der Schweiz 2008-2020, SBFI, https://www.sbfi.admin.ch/sbfi/de/home/dienstleistungen/publikationen/publikationsdatenbank/publikationen-08-20.html
[4] Betting big on quantum, McKinsey, https://www.mckinsey.com/featured-insights/coronavirus-leading-through-the-crisis/charting-the-path-to-the-next-normal/betting-big-on-quantum?cid=other-soc----oth---&sid=7607650673&linkId=181200916
[5] Betting big on quantum, McKinsey, https://www.mckinsey.com/featured-insights/coronavirus-leading-through-the-crisis/charting-the-path-to-the-next-normal/betting-big-on-quantum?cid=other-soc----oth---&sid=7607650673&linkId=181200916, additionally 150 million CHF since 2022 for the US: https://www.quantum.gov/quantum-in-the-chips-and-science-act-of-2022/
[6] Quantum information research in China, 2019, Pan et al., https://iopscience.iop.org/article/10.1088/2058-9565/ab4bea, How much money has China already invested into quantum technology? – Part II, Amara Graps, April 2022, https://quantumcomputingreport.com/how-much-money-has-china-already-invested-into-quantum-technology/
[7] A Quantum Revolution: Report on Global Policies for Quantum Technology, CIFAR, https://cifar.ca/cifarnews/2021/04/07/a-quantum-revolution-report-on-global-policies-for-quantum-technology/, Le rêve quantique chinois: les aspiration d'un géant dans l'infiniment petit: https://www.ifri.org/fr/publications/etudes-de-lifri/reve-quantique-chinois-aspirations-dun-geant-linfiniment-petit

and Technology (MOST), the Ministry of Industry and Information Technology (MIIT) and the NSFC. Additionally, municipal governments such as Beijing, major public banks and funds are involved.

On the side of research and education institutions, the University of Science and Technology (USTC) in Hefei plays a key role. Its department of research in physics and quantum information is headed by Pan Jianwei, who is also called “the father of quantum physics in China”. The USTC is involved in major research projects, it offers quantum-related academic programs, supports spin-offs in the field and collaborates with industry stakeholders, such as the China Shipbuilding Industry Corporation (CSIC) and Chinese defense conglomerates developing military applications, including quantum radar to detect stealth aircraft, quantum magnetometers to detect submarines, and quantum key distribution to enable encrypted communications. Together with institutes from all over China, the CAS and the USTC are currently building a new National Laboratory for Quantum Information Science, located in Hefei. The aim is for it to become the world’s largest quantum research facility, with a focus on computing and communication. Since the beginning of the Covid-19 Pandemic, the timeline of this project has become unclear.

Tsinghua University performs research in various quantum areas and together with the Beijing municipal government it initiated the Beijing Academy of Quantum Information Sciences (BAQIS). The National University of Technology and Defense (NUDT) and the People’s Liberation Army (PLA) have a big interest in quantum, but they do not seem to be central actors at the moment. However, it has to be noted that the above-mentioned institutions and also Pan Jiawei himself have close ties to the PLA.[8] The military interest in the field is not only due to its potential impacts on encryption technology, but also because a lot of quantum research has a dual-use character, ranging from highly developed sensors to sophisticated communication and computing infrastructure. Interesting to note is that more than half of China’s quantum patents since 2012 are in the field of Quantum Key Distribution (QKD), an encryption technology.[9]

Private Chinese companies are crucial in the development and upscaling of applications of quantum research.[10] In contrast to the academic sector, the private sector is much more involved in quantum computing than quantum communication.[11] Nevertheless, In the realm of strategically important technologies, private business actors rely on access to public funds and research projects, which entails the probability of political influence.

Most important tech giants in China (e.g. Alibaba, Tencent, Huawei, Baidu) have established their own quantum research initiatives, such as the Tencent Quantum Lab, or the HiQ platform of Huawei.[12] Besides the big tech companies, quantum start-ups are emerging with the support of the government, for instance XT Quantech, QuantumCtek or Origin Quantum. Most of them are spin-offs from research laboratories. Local governments have also established incubators for start-ups in the quantum field.[13]

Main areas of research
Hardware research development toward development quantum computers

Quantum communication

China has realized two flagship projects: Firstly, the ‘Beijing-Shanghai Quantum Secure Communication Backbone’, a secure quantum communication line, and the Quantum Experiments at Space Scale (QUESS) project, a satellite for quantum communication. Together, these projects represent the first integrated ground-based fiber-optic and

[8] https://www.scmp.com/news/china/science/article/3043596/chinas-father-quantum-pan-jianwei-has-ties-countrys-defence, https://www.ftm.eu/chinascienceinvestigation
[9] Quantum gold rush: the private funding pouring into quantum start-ups, Elizabeth Gibney, nature, https://www.nature.com/articles/d41586-019-02935-4
[10] https://www.scmp.com/news/china/science/article/3186402/chinese-companies-begin-embrace-quantum-technology
[11] Mapping the Chinese Private Actors Race to Quantum, Helene Lavoix, The Red Team Analysis Society, https://redanalysis.org/2019/09/09/mapping-the-chinese-private-actors-race-to-quantum/
[12] Baidu: https://www.reuters.com/technology/chinas-baidu-reveals-its-first-quantum-computer-called-qianshi-2022-08-25/, https://quantum.baidu.com/, Tencent: https://quantum.tencent.com/, Huawei: https://www.huaweicloud.com/intl/en-us/solution/hiq/ , Alibaba: https://www.alibabacloud.com/press-room/alibaba-cloud-and-cas-launch-one-of-the-worlds-most
[13] https://quantumcomputingreport.com/china-the-quantum-technology-landscape-part-3/, Figure 8 and Table 1

satellite quantum communication network worldwide.[14,15], Both research projects were led by Pan Jiawei from USTC.[16]

The secure communication line between Beijing and Shanghai was finalized in 2016 and further expanded to major cities such as Jinan and Hefei. It covers a distance of more than 2000 km and it uses Quantum Key Distribution (QKD) as a secure way of digital communication. The line is currently used for the transmission of governmental, financial and national defense information.[17]

As an expansion of the network, the Mozi satellite was launched in 2016 as part of the QUESS project. In 2017, the first quantum-secure intercontinental video conference was held via this satellite between Beijing and Vienna. In 2020, the exchange of quantum encryption keys was realized through the satellite without revealing the keys to the satellite. Originally, the satellite was built to last until 2021; it is currently still up and running and further experiments are expected. The further development of the apparently quantum-secure communication network is pushed forward by CAS Quantumnet, a hi-tech enterprise affiliated with CAS.[18,19]

Quantum Computing

China is one of the most advanced countries in photonic processors. At the end of 2020, a research team led by Pan Jianwei from USTC announced to have reached quantum advantage with the photonic processor Jiuzhang 2.0 with 113 qubits.[20] In 2019, the same research team announced to have proven the quantum advantage of a superconduction processor, the Zuchongzhi with its 66 qubits.[21] One and a half years after Google had announced to have surpassed this same barrier. However, even at a technical level it is unclear how quantum computers can be compared.

At the beginning of 2018, Alibaba, in cooperation with CAS, launched their first superconduction cloud-based quantum computer with 11 qubits. In the summer of 2022, Baidu launched its first quantum computer and the world's first all-platform quantum hardware-software integration solution, Liang Xi.[22]

Quantum Sensing/Metrology

Compared to the above-mentioned fields, research on quantum sensing/metrology is less of a national priority. Nevertheless, there are ongoing research projects of interest in cooperation with the National Time Service Center (NTSC) and the China Electronics and Standardization Institute (CESI). For instance, China wants to establish a time-frequency dissemination fiber network for timing synchronization.

Software research development

Besides the infrastructure and computing projects, China also invests in quantum software. An interesting example is the research on optical quantum computing algorithms at the USTC.[23] And with the above-mentioned all-platform solution Liang Xi, Baidu is currently the most interesting driver of quantum software development in China, with international outreach.

Outlook for the coming years

Despite a lot of advancements, quantum research still has a long way to go. China has made great achievements in the past years, but is mostly excelling in the applications of quantum research. Major breakthroughs in fundamental

[14] https://www.scmp.com/news/china/science/article/3174426/quantum-secure-communication-breakthrough-china-scientists?module=hard_link&pgtype=article

[15] Presentation at ITU Workshop on Quantum Information Technology (QIT) for Networks by CAS QUANTUMNET, https://www.itu.int/en/ITU-T/Workshops-and-Seminars/2019060507/Documents/Hao_Qin_Presentation.pdf

[16] http://www.xinhuanet.com/english/2021-01/07/c_139646744.htm, https://www.shine.cn/news/nation/2101072877/

[17] Presentation at ITU Workshop on Quantum Information Technology (QIT) for Networks by CAS QUANTUMNET, https://www.itu.int/en/ITU-T/Workshops-and-Seminars/2019060507/Documents/Hao_Qin_Presentation.pdf

[18] Presentation at ITU Workshop on Quantum Information Technology (QIT) for Networks by CAS QUANTUMNET, https://www.itu.int/en/ITU-T/Workshops-and-Seminars/2019060507/Documents/Hao_Qin_Presentation.pdf

[18] https://www.yicaiglobal.com/news/chinese-hi-tech-firm-unveils-world-first-crypto-cloud-quantum-communication-server

[20] https://www.globaltimes.cn/page/202110/1237312.shtml

[21] http://www.news.cn/english/2021-10/26/c_1310269887.htm#:~:text=In%20December%202020%2C%20the%20researchers,the%20world%27s%20fastest%20existing%20supercomputer.

[22] https://interestingengineering.com/innovation/baidu-released-first-superconducting-quantum-computer

[23] https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.99.250504

research are still missing. The focus on applied research seems to be a promising short-term strategy. It has to be seen if the sheer quantity of Chinese investment into the field will also result in fundamental breakthroughs in the long-term. Furthermore, the current strategy makes China more dependent from other countries, which is not in line with the strategic goal to achieve technological independence in key areas.

The ongoing communication projects are expected to be continued. The secure backbone quantum communication network is permanently being expanded, with a total goal of 35’000 km. The idea of a worldwide secure QKD-network (“quantum internet”) will probably be pushed forward by China. The earth-space quantum connection will most probably also be exploited militarily to push for Chinese space dominance.[24] China will also take further steps to ensure national security, such as establishing a national standard for quantum cryptography. So far, no programmable quantum computer has been developed. The above-mentioned computers can only execute specific calculations. It is expected that this development continues and ‘quantum supremacy’ will be shown in specialized processors or quantum simulators. Last but not least, China fosters the talent development in quantum by establishing training programs for specialists, strengthening academic programs and including quantum education into the education plans.[25]

International cooperation in quantum research

Quantum research in China has benefitted from international cooperation. A great number of its experts have studied abroad and returned to China with important know-how. For example, about a third of Pan Jianwei’s research group have studied or taught at the University of Heidelberg, Germany, where he still holds a honorary professorship.[26] However, international collaboration of Chinese quantum research groups is rare and declining. Because of its potential impact on information security and critical infrastructure, research in the field is expected to further raise geopolitical tensions, especially between the US and China. For instance, the US have already implemented sanctions against 28 quantum computing entities of China or with ties to China.[27] Internationally, alliances are being made. For instance, European countries, the US, Canada, Australia and Japan are currently building a quantum technology alliance of democracies.

Collaboration opportunities for Switzerland

Quantum research has become a geopolitical battlefield and cooperation between Switzerland and China in the field is delicate and needs to be well considered. In addition to substantial dual-use risks, decoupling tendencies between a western-influenced sphere of quantum research and a Chinese-influenced one is well underway. Switzerland-based researchers in the field are well advised to take heed of these tendencies and choose their partners accordingly. In general, cooperation on the software side might be less critical, as most of it is already open source and international security policies mostly target to regulate quantum hardware. Furthermore, quantum sensing and metrology might be a touching point for collaboration between Switzerland and China. The field is geopolitically less sensitive and Switzerland has a long tradition and expertise in the field of precision engineering. However, the field still has a high risk for dual-use applications and any breakthroughs in quantum sensing might also contribute towards quantum computers.

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[24] https://www.lowyinstitute.org/the-interpreter/where-quantum-satellites-fit-pla-strategy

[25] How is China Education a Quantum Workforce? – Part I, Amara Graps, April 2022 https://quantumcomputingreport.com/how-is-china-educating-a-quantum-workforce/

[26] https://www.scmp.com/news/china/science/article/3043596/chinas-father-quantum-pan-jianwei-has-ties-countrys-defence, https://www.ftm.eu/chinascienceinvestigation, https://www.physi.uni-heidelberg.de/Forschung/index.php?leiter=pan

[27] https://therecord.media/us-sanctions-28-quantum-computing-entities-in-china-russia-pakistan-japan/

As world leader in the production of computer chips, Taiwan is focusing on quantum computing and the potential development of quantum chips.

Quantum R&D in Taiwan

In December 2021, Taiwanese authorities have published plans to invest NT$8 billion (251.76 million CHF) into the establishment of a research and development platform on quantum technologies by 2026. Since then, a team of 17 research groups has been formed. The platform focuses on quantum computing and quantum communication, especially on the development and research of materials, Qubits, cryoelectric systems, quantum optics and detectors and chips for quantum communication. Regarding software development, a cooperation platform for the development of quantum algorithms and software design is planned, with a focus on quantum encryption and a quantum transfer protocol.

The authorities in Taiwan have started to show interest in the field at a relatively late stage, says Chi-Dong Chen, the Executive Officer of the Thematic Center of Quantum Computer of Academia Sinica. Besides the focus on quantum computing, he also sees a lot of potential for the development of quantum chips, as Taiwan is the world leader in the production of computer chips.

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Ideas & insights from the East

India

India

State of quantum research in India

India is preparing to play a key role in the coming quantum technology revolution, with big ambitions, and the requisite funding being committed. Most of the activity is currently concentrated in the public sector, but a quantum start-up ecosystem is taking shape and industry is showing interest and increasing its involvement in this sector. The public sector currently accounts for 92% of the initiatives under implementation[1].

> Quantum technologies, a mission of national importance, should reach critical maturity by 2026-27, and has the potential to add US$ 310 billion to the Indian economy by the year 2030.

Funding, and funding sources

The Government is the principal funder of quantum research in India. The Department of Science and Technology launched the Quantum-Enabled Science and Technology (QuEST) initiative by investing INR 80 crores (US$ 10 million approx.) to lay out infrastructure and to facilitate research in the field[2]. In her budget speech in 2020, noting that quantum technology is opening up new frontiers in computing, communications, cyber security with wide-spread applications, and anticipating commercial applications from theoretical constructs, India's finance minister had committed a sum of INR 8000 crores (US$ 1 billion approx.), over a period of five years, for the National Mission on Quantum Technologies and Applications (NM-QTA).[3] This represents the bulk of funding available for quantum research in India today. However, the private sector is slowly realising the possibilities and establishing partnerships, mainly with universities to develop capacities and develop new technologies for the future.[4]

Main actors, both public and private sectors

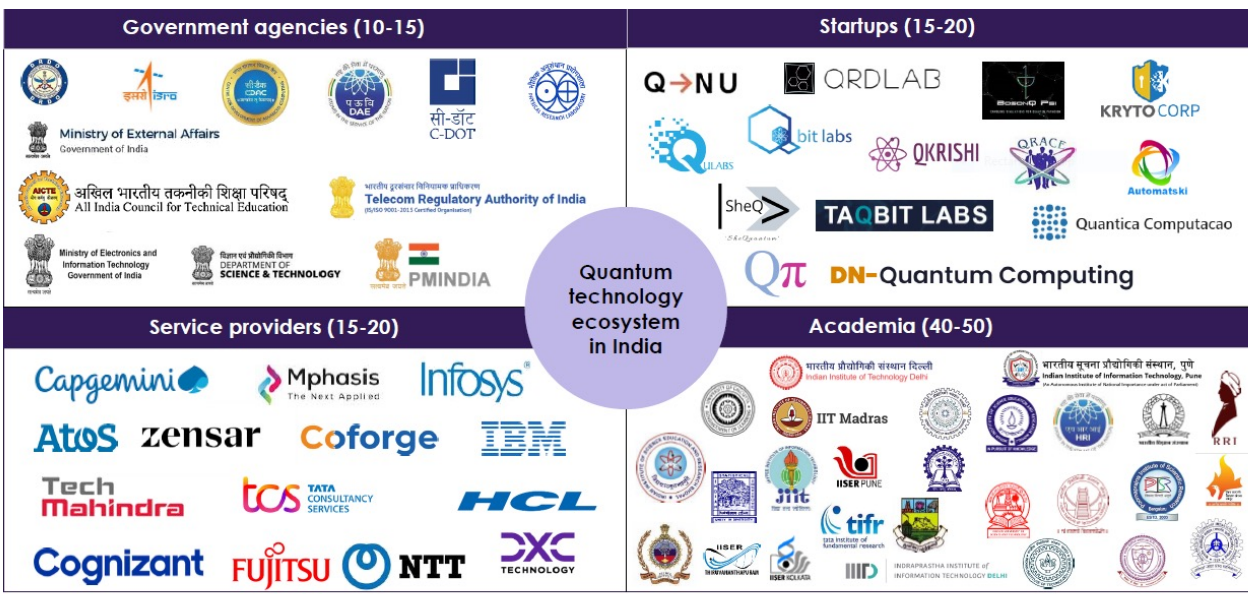
The principal actors in quantum technologies in India are in the public sector. The Department of Science and Technology has established the National Mission on Quantum Technologies and Applications, with the budgetary support mentioned above.[5] The Indian Space Research Organisation is working on satellite based quantum communication.[6] The Office of the Principal Scientific Adviser to the Government of India has set up the Quantum Frontier mission, to understand and control quantum mechanical systems and aims to develop quantum computers, quantum chemistry, quantum communication, new materials, quantum sensors, and

[1] https://community.nasscom.in/communities/it-services/quantum-revolution-india-betting-big-quantum-supremacy
[2] https://www.orfonline.org/expert-speak/indias-race-to-quantum-supremacy/
[3] https://www.indiabudget.gov.in/budget2020-21/doc/Budget_Speech.pdf
[4] https://www.livemint.com/technology/tech-news/it-firms-make-initial-forays-into-quantum-computing-11659553617908.html
[5] https://dst.gov.in/budget-2020-announces-rs-8000-cr-national-mission-quantum-technologies-applications
[6] https://www.isro.gov.in/DeptofSpace.html
[7] https://www.psa.gov.in/mission/quantum-frontier/26

quantum cryptography.[7] In addition to the agencies mentioned above, Department of Atomic Energy, the Defence Research and Development Organisation and the Ministry of Electronics and Information Technology are also involved in this mission.

Leading research institutions such as the Indian Institute of Science, the Indian Institutes of Technology, the Tata Institute of Fundamental Research, the Harish-Chandra Research Institute and the Raman Research Institute have set up laboratories dedicated to quantum computing and technology. This list is non-exhaustive as it is estimated that some 40 to 50 research groups are involved in quantum research in India. With the first start-ups in the quantum space being set up in 2017, there are now some 15 to 20 start-ups active in the field. It is expected that India will have between 400 to 500 over the next decade[8]. In addition, most of the major Indian service providers in the IT space, such as Tata Consultancy Services, Tech Mahindra, HCL and Infosys, as well as foreign ones, are active in quantum computing today now some 15 to 20 start-ups active in the field. A snapshot of the quantum technology ecosystem in India is given below. The ecosystem is expanding and is expected to continue to do so at an accelerated pace over the next 10 years.

The Quantum Ecosystems Technology Council of India[9], a not for profit company, brings together industry, academia and government on a common platform. It serves as a think tank and advisor to quantum technology stakeholders in India and enables international collaboration.



Source: The Quantum Revolution in India: Betting Big on Quantum Supremacy[10]

[8] https://www.computerweekly.com/news/252513355/India-to-invest-1bn-in-quantum-computing
[9] https://qetci.org/
[10] https://community.nasscom.in/communities/it-services/quantum-revolution-india-betting-big-quantum-supremacy

Outlook for the coming years

With the funding mechanisms from the Government in place, a rapidly expanding ecosystem and increasing interest from industry, quantum technology is expected to reach critical maturity in India by 2026-27. It is estimated that its adoption across industries has the potential to add $310 billion to the Indian economy by 2030[11].

Main areas of research

To prepare the future workforce for quantum computing in India, research organisations and the Ministry of Electronics and Information Technology have developed a toolkit, QSim, India's Quantum Computing Toolkit[12]. It brings together academicians, scientists, engineers and industry and offers a quantum computing simulator which can create quantum circuits and quantum programs.

The National Mission on Quantum Technologies and Applications, which is the main driver for research and uptake of quantum technologies in India, has a very ambitious programme. The scope of the mission includes research in frontier areas of quantum science and technology, information and quantum mechanics, quantum matter and materials, quantum computing, quantum communication, quantum cryptography, quantum metrology, quantum sensing and quantum-enhanced imaging. Vertical focus areas, which have been prioritised, include quantum clocks, quantum sensors, quantum imaging, quantum computing and quantum communications. The Mission aims to develop trained manpower for the quantum industry, with the objective of having 25,000 people trained, including 2000 PhDs in the next 5 to 7 years. It aims to help create, through seed funding, 800 start-ups in the domain, as well as to foster international collaboration. A 50-quibit quantum computer should be developed by 2026. The Centre for Development of Quantum Technology (in the process of being set up), an interdisciplinary collaboration centre for development of quantum technology with various wings around the country will be the primary agency to operationalise the mission[13].

The academic sector is already heavily engaged in research in quantum technologies. Fields of research include quantum technology development (core hardware and back-end engineering support), quantum game theory, quantum secure communication, quantum random number generation, quantum sensing and metrology, quantum phenomena in superconducting circuits, quantum optics, quantum information processing. In addition, algorithms for cryptography and machine learning and applications in quantum key distribution, quantum dense coding, quantum teleportation, quantum cryptography are also being developed.

India has achieved some success already. Scientists from the Space Applications Centre and Physical Research Laboratory have jointly demonstrated quantum entanglement based real time Quantum Key Distribution (QKD) over 300 metres in the air, along with quantum-secure text, image transmission and quantum-assisted two-way video calling[14]. The Centre for Development of Telematics has already filed two patents for Quantum key distribution[15]. The Quantum Information and Computing (QuIC) lab at the Raman Research Institute has demonstrated a quantum state estimation tool to understand properties of different types of light with a very high accuracy[16]. Indian researchers produced 3.9% of all quantum related publications in the world in the period 2016-2020, ranking sixth in terms of scientific production. 72% of these publications result from international cooperation[17].

International cooperation in quantum research

India has a few active international cooperation programmes in quantum research already. India and Finland have set up an Indo-Finnish Virtual Network Centre on Quantum Computing with the aim of building superconducting quantum computers in India[18]. India and Israel are collaborating on quantum devices and quantum technologies for sensing imaging and communication[19]. India and Australia have created a corpus to fund research, and development on artificial intelligence, quantum

[11] See above
[12] https://qctoolkit.in/
[13] https://tifac.org.in/images/nmqta/concept_note12.06.19.pdf
[14] https://www.isro.gov.in/DeptofSpace.html
[15] https://www.cdot.in/cdotweb/web/product_page.php?lang=en&catId=1&pId=48
[16] https://www.rri.res.in/quic/research.php
[17] Scientific publications in Switzerland, 2008–2020 A bibliometric analysis of scientific research in Switzerland https://www.sbfi.admin.ch/sbfi/en/home/services/publications/data-base-publications/publications-08-20.html
[18] https://dst.gov.in/india-finland-discuss-possible-areas-co-operation-quantum-computing-virtual-coe

computing, and robotics, with the objective of improving their cyber resilience[20]. The BRICS countries (Brazil, Russia, India, China and South Africa) have set up the BRICS Virtual Institute of Photonics, which includes quantum technologies[21]. India and the European Union have recently signed an agreement for cooperation on high performance computing, weather extremes and climate modelling, and quantum technologies[22].

Collaboration opportunities for Switzerland

Several avenues for cooperation between Switzerland and India can be envisaged. The Department of Science and Technology of the Government of India, the principal funding agency for basic research, has expressed an interest to collaborate with Switzerland, amongst others, in the areas of artificial intelligence and quantum science and technology, which would generate societal benefits. Interest within the stakeholders in Switzerland and in India could be explored. Quantum Technology (computing and communications) will be a focus are for the year 2023 for HCL, one of India's largest IT companies. There is an interest from the company to connect with startups and academia in Switzerland and this will be explored further. Finally, the Group Leader of the Quantum Information and Computing (QuIC) lab at the Raman Research Institute[23] is a member of the Geneva Science and Diplomacy Anticipator (GESDA) Open Quantum Initiative core task force. This connection can be leveraged to explore opportunities for Switzerland in quantum research collaboration with India.

[19] https://dst.gov.in/sites/default/files/For%20website%20-CFP%20India-Israel%202020-2022.pdf
[20] https://india.highcommission.gov.au/ndli/AICCTP.html
[21] http://virtualinstitute.info/
[22] https://digital-strategy.ec.europa.eu/en/news/india-and-eu-sign-intent-cooperation-agreement-high-performance-computing-and-quantum-technologies
[23] https://sites.google.com/site/urbasisinha/home

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Ideas & insights from the East

Japan

Japan

State of quantum research

Japan has been leading basic research on quantum technologies. It was Prof. H. Nishimori of the Tokyo Institute of Technology who invented the concept of Quantum Annealing in 1998. The following year, Prof. Y. Nakamura and Prof. J.S. Tsia of NEC developed the superconducting qubit.

Quantum technology has been one of the strategic focus areas in Japan's science, technology and innovation policy. Now, the country is accelerating its efforts to maintain and improve competitiveness in the field. The Prime Minister himself in his New Form of Capitalism policy places quantum technology on the top of the list of focus areas for investments, along with AI, biotechnology, digital and decarbonization.

1-1. Funding, and funding sources

In Japan, the main source of funding continues to be government spending which is growing fast. The total budget allocated for fiscal year (FY) 2022 including the supplementary budget for the previous FY was appx. 79 billion yen (USD 550 million), more than double that of the comparable total of 35 billion yen for the previous year.

1-2. Main actors, both public and private sectors

The Quantum Technology Innovation Hubs Headquarters, established under the Quantum Technology Innovation Strategy formulated in January 2020, is based at RIKEN, Japan's largest research institution. Under this Headquarters there are ten Hubs based in different research institutions and universities, namely the RIKEN Center for Quantum Computing (RQC), the Quantum sensing hub at the Tokyo Institute of Technology, the Quantum material hub at the National Institute for Material Science (NIMS), the Quantum Software Research Hub at Osaka University, the Quantum computer applications hub at the University of Tokyo with business partners, the Quantum life science hub at the National Institutes for Quantum and Radiological Science and Technology (QST), the Quantum security hub at the National Institute of Information and Communications Technology (NICT), the Quantum device development hub at the National Institute for Advanced Industrial Science and Technology (AIST), the Quantum solutions hub at Tohoku University and the Quantum technology international collaboration hub at the Okinawa Institute of Science and Technology (OIST), with the latter two being added in April 2022.

> Japan is investing heavily into quantum to improve global competitiveness and become a quantum hotspot. Switzerland is a welcomed partner, with additional funds for exchanges expected.

Additionally, Goal 6 of Japan's flagship Moonshot R&D funding program is the Realization of a fault-tolerant universal quantum computer that will revolutionize economy, industry and security by 2050. The programme, funded by the Japan Science and Technology Agency (JST), has an expected budget of ¥ 15-20 billion. Researchers contributing to this project include top universities as well as industry giants such as Hitachi Ltd. and NEC Corp. additional quantum related publicly funded projects include additional institutions such as Kyushu University, Kyoto University, Kyoto Institute of Technology, Tokyo University of Science, Keio University and Waseda University.

While there is only one main quantum technology consortium in the U.S. and E.U., there are five such associations in Japan. The Quantum Strategic industry Alliance for Revolution (Q-STAR) is the only government initiative under the Ministry of Economy, Trade and Industry (METI). Established in 2021, Q-STAR is an alliance of private sector actors (companies and startups) wanting to take initiative in using quantum technologies. It has 61 members as of Oct 5, 2022, including household names such as Toyota Motor Corp., Hitachi Ltd., Toshiba Corp., Nippon Telegraph and Telephone Corp. (NTT), Fujitsu Ltd., and NEC. An interesting characteristic about the other four groups, namely the Quantum ICT Forum, Quantum Innovation Initiative Consortium (QII), Quantum Software Research Hub (QSRH) and Quantum Practical Application Research Consortium (QPARC) are that they include companies not only engaged in developing quantum technology but those looking to apply the technology to their business from various fields such as chemical, financial, pharmaceutical, energy, electronics, heavy industry and trade.

There are ten start-ups in the quantum field, a comparable figure to the six in Switzerland, according to the Quantum Computing Report. All ten are considered as software or consulting while Swiss start-ups are either hardware, communications or more.

1-3. Outlook for the coming years

In April 2022, the Japanese government announced its new Vision of Quantum Future Society that expanded on the 2020 strategy with initiatives for social innovation through quantum. A wide variety of potential use cases were introduced, ranging from quantum computers for smart factory, financial / transportation / logistic / smart grid systems, carbon neutral materials development and disaster prevention, quantum sensing for electric vehicle batteries, brain machine interfaces and for medical/pharmaceutical use. More quantitatively, the Vision envisions to service its first home-made quantum computer by March 2023 and having 10 million people using the technology by 2030. The strategy aims to increase R&D, increase production value by quantum technology to 50 trillion yen by 2030, and encourage the development of made-in-Japan quantum computers.

Main areas of research

2-1. Hardware research development toward development quantum computers

As Japan strives to introduce its first domestic quantum computer, Fujitsu and RIKEN are reportedly preparing to provide superconducting quantum computers in FY 2023, anticipating use in financial market prediction and development of new materials and pharmaceuticals. They aim to release a 64-qubit machine in 2023 and a 1000-plus-qubit machine in 2026. This supercomputer will be made available to any interested research parties. The two partners had established a collaboration center at RQC in 2021. NEC has joined forces with AIST to advance its superconducting-circuit quantum annealing technology by initially introducing an application-specific solution for logistics route optimization in 2023.

Meanwhile, Hitachi is working on silicon quantum computers also under the Moonshot Goal 6. The development originated at its Cambridge Laboratory collaborates with EPFL, most recently on a CMOS-based chip that integrates silicon quantum dots and multiplexed readout electronics.

IBM installed one of the world's first quantum computers, System One, in Kawasaki, Kanagawa, as a result of the Japan-IBM Quantum Partnership with the University of Tokyo. Prior to this, the first commercial IBM Quantum Hub in Asia was made available in 2018 at Keio University.

At this stage, companies and research institutes are working on various quantum technologies. On the contrary, RIKEN also works on scalable silicon quantum computer technology under the Moonshot Goal 6. The R&D program also covers trapped ion, neutral atom and optical quantum computing technologies basically covering all the bases.

Recent breakthroughs include Toshiba achieving quantum communications over optical fibers exceeding 600 km in length, a world record, and RIKEN entangling three qubits on silicon (both in 2021). Furthermore, Yokohama University researchers demonstrating universal holonomic quantum gates (2018).

In addition to these R&D hubs, Japan is home to the sole global manufacturer of superconducting cables suitable for quantum computers, Coax Co. Furthermore, NF Holdings Corp. is the only major provider of low noise power supplies. The two companies that offers suitable connectors are also from Japan; Japan Aviation Electronics Industry, Ltd. and Kawashima Packaging Machinery Ltd. The Japanese are also prominently present in the fields of control devices, low noise amplifiers and dilution refrigerators.

2-2. Software research development

The main hub for quantum software research in Japan is QSRH hosted at Osaka University's Center for Quantum Information and Quantum Biology. Currently, QSRH works on seven projects; (1) cultivation of quantum computing technology community and talents (2) development of applications for machine learning, mathematical and data science and the financial sector (3) applications to advance the fields of material, chemical and condensed matters (4) software infrastructure tools to enhance the capabilities of NISQ machines and fault-tolerant quantum computers (5) cloud environment for integrated control of quantum and conventional computers (6) general purpose middleware for platforms the use of which can be defined by quantum software and (7) quantum computer test beds applicable for all types of quantum computers for quantum software developers.

Members of QSRH include Bridgestone Corp., Mitsubishi Corp., Mitsubishi Heavy Industries Ltd., Toyota Central R&D Labs, JX Nippon Oil & Gas Exploration Corp., Iwatani Corp., MS & AD Insurance Group Holdings, Daiwa Securities Group Inc., Roche Group company Chugai Pharmaceutical Co., KDDI Corp., Panasonic Corp., Sony Group. Corp. and more, in addition to universities (Kyoto University and Kanazawa Institute of Technology) and start-ups such as QuEL Inc. and QunaSys Inc. Other relevant actors include MDR Inc, Jij Inc. and Fixstars Corp.

Recently, University of Tokyo researchers developed a systematic method that applies optimal control theory to identify the theoretically optimal sequence from among all conceivable quantum operation sequences (2022).

International cooperation in quantum research

Japan has been focusing its efforts to strengthen ties with the US and EU. In 2019, Japan signed the Tokyo Statement on Quantum Cooperation with the US, which was elevated two years later into an Implementation Agreement under the S&T Cooperation Agreement. Cooperation between the two countries are intensifying not only in research but also in policy dialogues in light of the tension between the US and China. The EU is positioned as the other strong partner, with the two sides agreeing on cooperation since 2018.

This has led to the Japan hosting its first Quantum Innovation Symposium with mainly US and EU partners in December 2021. The second international symposium on quantum science, technology and innovation will be held on 28-30 November 2022. While the US and EU are the most visible partners, collaboration with Switzerland is also present. For example, three speakers were invited from Switzerland to the Innovation Symposium 2022 amongst presenters who were dominantly from Japan, North America and the EU.

Collaboration opportunities for Switzerland

While Japan has its attention centred on the US and EU, Switzerland is highly respected for its excellent research. This can be seen from the fact that three speakers from Switzerland were invited to the Quantum Innovation Symposium amongst presenters who were dominantly from Japan, North America and EU countries. Switzerland is well-positioned to be welcomed as a partner, with Japan seeking to work with like-minded countries.' As Japan rapidly grows its R&D in the field of quantum science and technology, it is seeking more and more talents.

In particular, researcher exchanges are sought in the fields of Atom Molecular Optics (AMO), condensed matter physics, quantum electronics and software for quantum computing where Switzerland has much to offer, based on the activities of NCCR SPIN and former NCCR QSIT. Swiss researchers should see more opportunities to invite Japanese counterparts and to be invited to Japan at least for the next three years.

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Ideas & insights from the East

South Korea

South Korea

State of quantum research

> With a length of 800 km, the Korean QKDN infrastructure secures the communication of 48 government bodies across the country, the largest quantum cryptography network outside China.

The immense volume of data, high security risks, and the need for super accuracy for detecting and sensing are driving the development of quantum technologies in Korea. In 2019 the Republic of Korea's Ministry of Science and ICT (MSIT) announced the investment of $40 million in quantum computing over the following five years, to develop core technologies such as quantum computer hardware and Quantum Computing New Architecture, Quantum Algorithms, Infrastructure, etc. An additional investment of $11.9 million regarded the next-generation ICT technology including ultra high-performance computing knowledge data convergence, system software, software engineering, information and intelligence systems, and human-computer Interaction (HCI). Despite the relatively small investment if compared with what assured by countries leader in the sector, the Korean government planned to complete demonstration of the practical 5-qubit (qubit information unit) quantum computer system with more than 90 percent reliability by 2023. In addition, it aimed to foster more than 33 quantum computing research groups including 7 key teams for core technology of quantum computing and 26 teams for promising technologies. By comparison, at the time of the announcement IBM had already unveiled its 20 qubit IBM Q System One.

Three years after in 2022, current South Korean Minister of Science and ICT, Lee Jong-ho, admitted a technology gap between South Korean companies and competitors in the United States and China. However, he also acknowledged that the next five years will be a very important turning point for the quantum ecosystem as quantum technology is forecast to be widely utilized in our daily life. If South Korea hesitates now, it may never find a timely opportunity to secure competitiveness in quantum technology. For this reason, on June 2022 a task force for the establishment of a 50-qubit quantum computer and quantum internet development was launched. Considering South Korean current technological capabilities and size of workforce the goal is a difficult challenge. Still, this is something the Country must take on through the cooperation of all industries, academia and institutions, according to the Ministry of Science and ICT.

Quantum technology is in a transitional stage as global key players such as Google, Microsoft, IBM, Honeywell, and Alibaba are pushing forward commercialization. Consequently, immediate demand for quantum will be mainly from research institutes. According to Korean strategy, the research community will provide the bridge to industrial use of quantum.

Main areas of research

In April 2021 a roadmap for quantum technologies was presented with focus on the following three main areas and sub-focuses:

Quantum Computing: algorithms; error correction applications; processors; quantum;

Quantum Communications: upgrading Korea's advanced fixed line quantum cryptography communication technology; leading international standardization; expanding coverage of the wireless cryptography communications;

Quantum Sensors: fund demand-driven R&D to expedite commercialization as the market demand for quantum sensors will be significant.

Most of all, quantum cryptography communications technology demonstrated its potential to be commercialized. Since 2020, as a part of the Digital New Deal initiative, pilot-types of quantum cryptography networks have been deployed across the 26 public and private institutes. Such pilot project aims to enhance physical security while attracting the private sector's interest, creating a virtuous cycle between research institutes and industries.

Korea Research Institute of Standards and Science (KRISS) recently unveiled its plan to complete the development of a superconducting 50-qubit quantum computer by 2026, and its goal to become a third country to build such computer by itself, following the United States and China. Meanwhile, Electronics and Telecommunications Research Institute (ETRI) and Korea Institute of Science and Technology (KIST) announced their commitment to secure key quantum memory technologies that are essential to store quantum data, and to develop a fixed/wireless repeater to transmit quantum data by 2026. Quantum data cannot be transmitted over the existing network. Their goal is to provide a quantum internet pilot service from 2036.

A concrete example of cross-sector cooperation is represented by the recently signed agreement between SDT, a Hardware-as-a-Service (HaaS) startup, and KIST to develop quantum cryptography devices in Korea for global commercialization as a result of technology transfer. One of the technologies transferred is 'Quantum Key Distribution' (QKD), a system that prevents unauthorized man-in-the-middle attacks from gaining access to sensitive data, as any communication interception changes the nature of the data itself. A major difficulty of establishing QKD networks has been the 1x1 barrier, or a communication system that connects only one receiver to one transmitter, which has limited use cases in real networks. The QKD solution developed at KIST solves this problem with a 1xN (one-to-many) communication system. SDT provides the physical implementation of the QKD and connectivity to an organization's current data storage network with plug-and-play architecture. The two contributions highlight the added value of cooperation between academia and industry. However, when it comes to QKD a major national project which involves a Swiss partner is reported at the end of this document.

Securing next-generation national competitiveness in the related field is the goal of the Quantum Technology Institute, which carries out a broad range of R&D projects on novel measurement standard research fields for next-generation quantum computing, quantum communications, and quantum sensors. The institute develops methods to measure and control quantized physical quantities such as photons, atoms, electrons, and phonons, and to generate and control quantum mechanical effects such as qubits and quantum entanglement. Such quantum technologies can realize new measurement standards (Josephson voltage standard, quantum Hall resistance standard, optical lattice clock etc.), next-generation computing (quantum computers), secure cryptosystems (quantum key distribution), and ultra-high-sensitivity sensing and imaging (quantum sensors). Through these research areas, the Institute aims to develop key technologies and achieve research excellence to lay the foundations for new future-oriented industries that beat the classical limits.

With a strong focus on quantum science and aiming to **raise national competitiveness in the basic science area, the Center for Quantum Nanoscience** (QNS) was established in 2017 as a part of the Institute of Basic Science (IBS), under the Ministry of Science and ICT. QNS is laying the foundation for future technology by exploring the use of quantum behavior atom by atom on surfaces with highest precision. Goals of the Center are driven to discover and develop scientific tools in order to achieve full control of the quantum states of atoms and molecules on clean surfaces and near interfaces, seek, both theoretically and experimentally, systems and strategies for engineering and coherent manipulation of quantum nanostructures, and explore and develop the use of single atoms and molecules as quantum bits for quantum computation using a ‘bottom-up approach’.

International cooperation in quantum research

A quantum information cooperative research institute was established in the US as a follow-up measure to the Korea-US presidential summit on May 2022. Intensive research development and close collaboration will help advance the quantum computing technology. However, independently on the bond with the US, Korea seems to point on cross-sector cooperation at national and international level rather than government to government agreements.

On 2021, IBM and Yonsei University announced that Korea is expected to become the fourth country in the world to have an on-premises IBM Quantum System One after the United States, Germany, and Japan. This milestone ushers in a new era of quantum workforce development in Korea to foster about 1,000 researchers and scientists by 2030. As part of the planned collaboration, Yonsei intends to work with IBM to advance quantum computing and grow the pool of quantum talent, with a goal to make quantum computing practical for the benefit of industry, science and society. This next-generation national quantum competency will follow Korea’s already established model in building previous competencies in the semiconductor, electronics, and automobile technology areas.

A major Swiss player in the quantum technology sector ID Quantique (IDQ) and the national telecommunication company SK Broadband (SKB) installed the most advanced key management, configuration, and monitoring solution to ensure smooth point to point connection, as well as the agility to adapt to specific local regulations. At the origin of the cooperation, the request from the Korean government for a solution to protect sensitive information and communications between its most critical government agencies, including the Ministry of Employment and Labor, the Ministry of Economy and Finance, and the Ministry of Education and local governments. The plan was to integrate each department’s network into one single convergence one, but what made the project even more challenging was the physical distance between them. With a total length of 800 km, this Korean Quantum Key Distribution network infrastructure, installed by IDQ and SKB, secures the communication network of 48 government organizations across the country, which makes it the largest quantum cryptography network outside China. Moreover, the telecommunication company SK invested in IDQ $65 million back in 2018.

Collaboration opportunities for Switzerland

As reported in the previous paragraph one of the major Swiss player in the quantum industry is active part of large scale projects and business in South Korea. Due to the size of the country and the physical distance between the departments involved in the network, South Korean’s model could be extended to other countries presenting similar characteristics. This opportunity might reinforce the image of the country in the quantum technology scene and broaden the business opportunities for IDQ.

Following the example of IDQ, SK and Samsung, the complementarity between Switzerland and Korea might pave the way to the translation of research outcomes - achieved by Swiss research organizations and agile small companies - into large scale commercial applications by South Korean big industrial players.

In addition, SK Telecom and Samsung Electronics have released the Galaxy Quantum 3, the world’s first 5G smartphone equipped with a quantum random number generator (QRNG) chip. The phone incorporates IDQ’s QRNG chip to provide secure cryptographic keys for encryption. Thanks to this chip it is a lot more difficult to hack without physical contact with the device. Users can access services and applications with more safety.

nextrends Asia
Ideas & insights from the East

Singapore

Singapore

Singapore had started funding quantum technologies as early as 2002 and has since then continuously expanded its efforts naming it a “key research area”[1] with more than 300 million Dollars invested – 170 million of which in the last 5 years alone.[2] The increase in funding serves to expand the quantum capabilities from research to commercialisation with plans to build Singapore’s own quantum computer, but also goes together with deeper coordination and governance of the tightknit quantum ecosystem on the small island nation.

> Singapore invested +$300 million in Quantum Technologies with capabilities in quantum computing, communications and sensing, positioning itself as a fast follower hungry for talent.

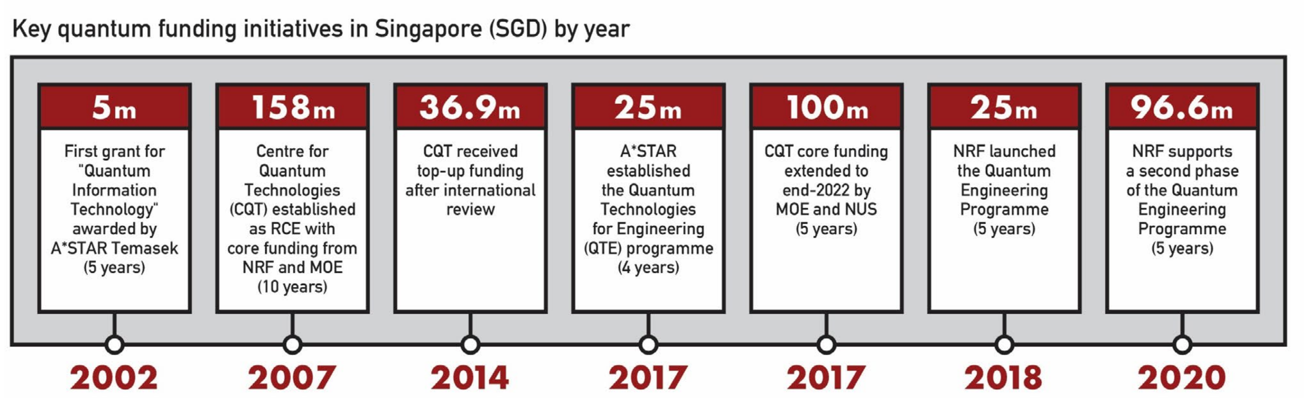

Figure 1: Presentation by Quantum Engineering Programme (2022) Source: QuantumSG.org

[1] www.pmo.gov.sg/Newsroom/DPM-Heng-Swee-Keat-at-Asia-Tech-X-Singapore-Summit-2022
[2] Presentation by Quantum Engineering Programm 2022

The National Research Foundation (NRF), which since 2006 sets the national direction for research and development (R&D), established the Centre for Quantum Technologies (CQT) as the first research centre of excellence in 2007.[3] Hosted by the National University of Singapore, CQT has grown to be the linchpin of Singapore's quantum research base with research excellence in the areas of quantum information, optics, communication, cryptography and simulation.[4]

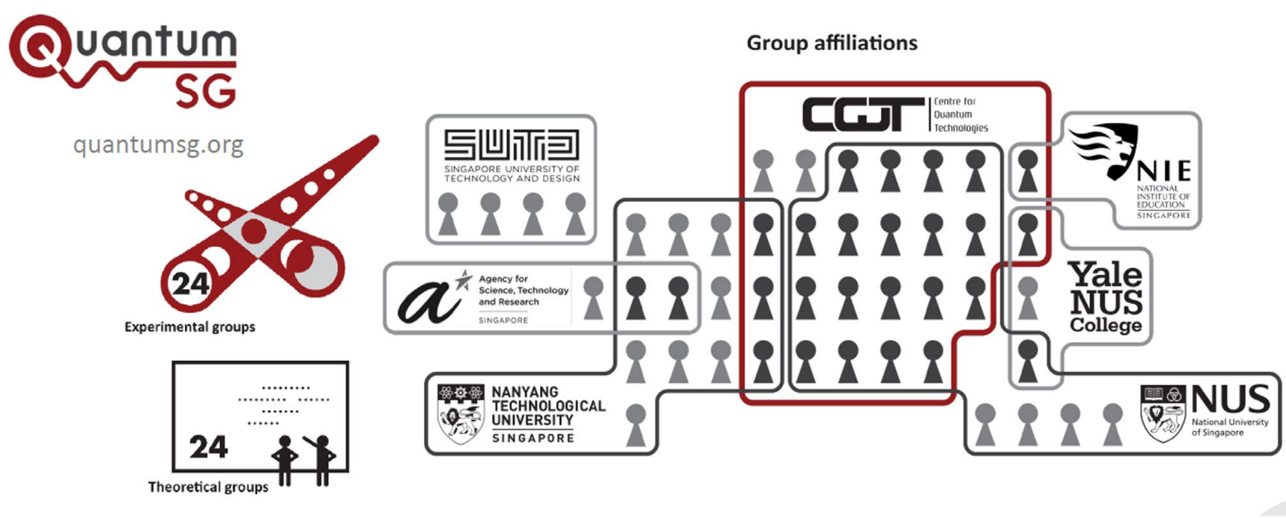

Figure 2: Singapore's research base in 2022, Presentation by Quantum Engineering Programme (2022) Source: QuantumSG.org

To build on the country's strength in quantum science, the Quantum Engineering Programme (QEP) was launched in 2018 to help researchers translate quantum research and development into commercial and industrial products. QEPs focus has since expanded to develop a quantum supply chain, contribute to national problems and explore use-cases. Both CQT and QEP are overseen by the National Quantum Office (NQO), which is responsible for the creation and implementation of Singapore's National Quantum Strategy.[5]

[3] www.nrf.gov.sg/about-nrf/national-research-foundation-singapore/nrf-milestones
[4] Quantum Technologies in Singapore – preparing for the future, quantumsg.org (2019)
[5] www.opengovasia.com/singapore-and-finland-partner-to-boost-quantum-tech/

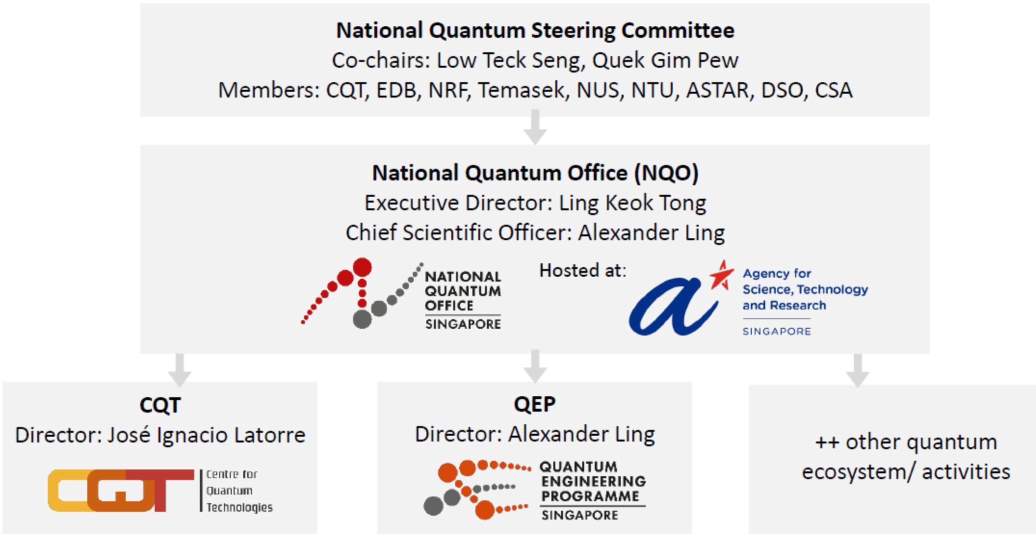

Figure 3: Presentation, Governance and coordination, Quantum Engineering Programme
Source: Quantum Engineering Programme

Generally Singapore encourages its researchers to commercialise their quantum capabilities, which has led to several spin-offs and start-ups. The seed financing is often provided by SGInnovate a government-owned innovation platform and venture capital firm, which has already supported such Singaporean ventures as Atomionics, Entropica Labs, Horizon Quantum Computing, and SpeQtral.[6] They also run an international internship placement program, where SGInnovate offers internships in the start-ups that they invested.[7] The Temasek foundation has also been active in supporting S-Fifteen Instruments, which builds instruments for quantum applications.[8] The startup ecosystem ranges from advanced instruments, quantum sensing to as quantum computing software.

Singapore's five year plan for research and development (RIE2025) identifies quantum as one of their "core digital capabilities" and vows to expand competence in new areas, such as quantum communications and quantum key distribution, quantum sensing and imaging, as well as quantum algorithms.[9]

Main areas of research

Singapore has bundled the knowledge and resources from National University of Singapore and Nanyang Technological University Singapore, A*STAR's Institute of High-Performance Computing, Institute of Materials Research and Engineering, and the Singapore National Supercomputing Centre into three national programmes.

Quantum Computing & Processors:
National Quantum Computing Hub: Building capabilities from hardware, middleware to applications of quantum computing.[10]

[6] Commercialising Quantum Technologies in Singapore, SGInnovate Insights (2020)
[7] www.sginnovate.com/apprenticeship/talent
[8] www.techinasia.com/wave-quantum-tech-startups-singapore-hopes-mark
[9] www.nrf.gov.sg/rie2025-plan
[10] www.nqch.sg/

Quantum Communication &Security:
National Quantum-Safe Network: Nationwide platform and a field-deployed testbed for a systematic construction of quantum-safe communication technologies.[11]

Quantum Sensors:
National Quantum Fabless Foundry: Developing quantum devices that require micro and nano fabrications and build home-grown quantum production and eventually quantum computers.[12]

International cooperation in quantum research

Singapore aims to become an international hub in quantum technologies despite its tiny size, which makes it critical to attract and develop talents from all over Asia and the world. Thus Singapore is looking to expand and maintain the network of international collaborations.

The most recent and highest level collaboration on a national level is the MoU between the National Quantum Office of Singapore and VTT Technical Research Centre of Finland, IQM Quantum Computers and CSC - IT Center for Science (Finland) signed in March 2022. The partnership is supposed to increase research collaborations and inform national strategic roadmaps on quantum technologies. Further cooperation is driven by the individual institutions involved in quantum research in Singapore, chief among them the Centre for Quantum Technologies (CQT). The network of CQT at NUS is vast with especially close ties to Europe. On an institutional level there are among others close ties to institutions in France (Majulab[13], Thales[14]) and Australia (University of New South Wales), AWS[15] and IBM Quantum[16].

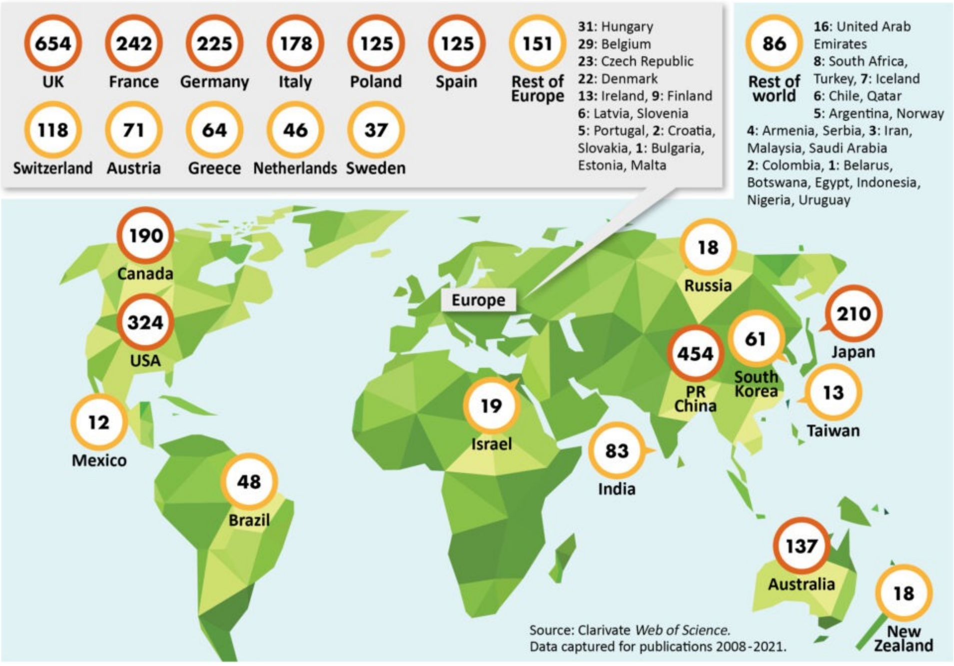

Figure 4: Counts of co-authorships by country of CQT researchers since 2007
Source: CQT

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[11] www.nqsn.sg
[12] www.a-star.edu.sg/imre/research-departments/national-quantum-fabless-foundry
[13] www.majulab.cnrs.fr/
[14] www.thalesgroup.com/en/singapore/press-release/new-partnership-between-qep-and-thales-spur-innovation-quantum-security-and
[15] https://news.nus.edu.sg/quantum-engineering-programme-teams-with-amazon-web/
[16] www.quantumlah.org/international-collaborations/

Collaboration opportunities for Switzerland

Singapore has ample funding through their national research programs and due to the small population a need to attract talent and retain it. The focus of collaborations should thus be on deepening existing networks and to build up a common talent pool. Many of the senior researchers at the Centre of Quantum Technologies (CQT) have an educational background at Swiss Universities such as the ETH Zürich, the EPFL or the University of Geneva and often have established but non-formal research collaborations with Swiss researchers. These informal links should be used as entry points to establish programmes with the aim of joint talent development. This could start at the attraction of talent with internship programmes (e.g. SGInnovates Summation-programme)[17] to expand the pool of future researchers and continue with collaborative workshops between research groups in Singapore and Switzerland. In regards to topic areas the tiny size of Singapore can be a considerable advantage because of the ability to serve as a nationwide testbed of quantum-safe communication. Additionally, since 2019 the National University of Singapore offers a specialisation in quantum technologies for physics undergraduates,[18] which would offer the potential on student-level collaboration and/or exchanges with the newly established quantum programmes at Swiss institutions such as EPFL and ETHZ.

[17] www.sginnovate.com/apprenticeship/talent
[18] www.physics.nus.edu.sg/student/specialisation-in-quantum-technologies/

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The Swissnex Network in Asia collaborates with a broad spectrum of partners related to international research and innovation, supporting them in their outreach and active engagement in the global exchange of knowledge, ideas and talent. Swissnex is an initiative of the State Secretariat for Education, Research and Innovation and is part of the Confederation's network abroad managed by the Federal Department of Foreign Affairs. The activities of the Swissnex Network in Asia are based on a collaborative approach, relying on public and private partnerships and funding.