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Swiss Quantum Initiative

Swiss Quantum Strategy

by the Swiss Quantum Commission (SQC)
as part of the Swiss Quantum Initiative (SQI)

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This report can be downloaded free of charges from quantum.scnat.ch/strategy

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Content

1 Preface

Building on decades of education, research and innovation, Switzerland offers a unique environment for quantum science and technologies. Excellent research, strong deep tech and industrial expertise are all embedded in a reliable societal and political framework. And given Switzerland's size, most distances between players are short – with many close ties. Located at the heart of Europe and in close collaboration with its international partners, Switzerland is set to play a key role in shaping the future of quantum science and technology for years and decades to come.[1, 2, 3] However, there is considerable scope for enhancing the connection between academic excellence and emerging applications, entrepreneurship, as well as the scaling of technologies.

The SQI, launched by the Swiss Federal Council in May 2022, aims to further strengthen Switzerland's excellent position in quantum science and technology – from fundamental research to industrial application. Part of these efforts includes the mandate for the SQC of the Swiss Academy of Sciences (SCNAT) to define a quantum strategy for Switzerland. This strategy provides direction and guidance to support the Swiss quantum ecosystem and to use resources effectively towards common goals. In the Swiss spirit, this document is expert driven. Switzerland is strong in bottom-up innovation, and as such, this strategy will evolve further with continued stakeholder dialogue.

Switzerland has a robust base and ambitious goals in all areas of quantum technologies, namely quantum communication, quantum computation, quantum simulation, as well as quantum sensing and metrology. While these fields have certain challenges and ambitions in common, they have specific characteristics and are at different stages of maturity.[A]

Considering both the significant potential benefits for society and international developments in the field of quantum, considerable further action and additional investments – public and private – are required to deliver on the overarching goals of the initiative: to ensure Switzerland is at the forefront of the next quantum era, to catalyze the creation of high-value jobs and to deliver value for society. For this, strengthening the position of Switzerland along the entire quantum value chain is imperative to remain competitive at an international level.

The SQC recommends significantly strengthening and accelerating Swiss efforts to scale and commercialize quantum technologies. To achieve this, progress in mid-range technology readiness levels (TRLs) is mission-critical, to be achieved via a set of strong, focused quantum technology centers, research and technology organisations (RTOs) and key players. With increasing TRLs and commercialization[B] over the next years, the portfolio of publicly and privately funded efforts needs to be bold and focused. Building on successful work at Swiss academic quantum centers, RTOs and private companies, application-oriented engineers and academic staff must work ever more collaboratively on mission-driven research and innovation.

Similar to approaches in other countries,[4] the design and setup of a Swiss deep tech fund is strongly recommended. This will allow startups and small and medium-sized enterprises (SMEs) to better scale while keeping their value creation and IP in Switzerland. Further, a culture of early adopters needs to be crafted and strongly promoted. For lower TRLs, funding for more fundamental research with a bottom-up approach including structures like National Centres of Competence in Research (NCCRs)[5] should be continued. As a basis for these efforts, the already strong education system in Switzerland continues to be a solid and incredibly valuable anchor point.

The following sections 2 to 4 define the vision, underlying principles and the overall strategic direction of the Swiss quantum ecosystem. Section 5 contains a more technical outline for each of the four thematic areas of quantum technologies. Key recommendations for the way forward are summarized in section 6.

A This strategy is linked to related fields and initiatives, notably the National Cyberstrategy[28] of Switzerland – without duplicating efforts. For example, classical approaches to post-quantum cryptography[38] are not addressed in detail in this paper.

B While several parts of this strategy focus on success-critical technological challenges, it should be noted that commercialization (market readiness) also includes factors such as unit costs and device usability.

2 Vision and principles

Figure 1: Vision statement

Switzerland – an international hub for quantum science, education, and innovation.

Offering a world-class environment where scientists, engineers, entrepreneurs, investors and companies of all sizes build and harness quantum technologies.

Being an **international hub** means Switzerland attracts leading quantum scientists, engineers, entrepreneurs, and investors from around the globe to foster a vibrant and diverse community that drives innovation[1] and, ultimately, delivers value for society. It also means Switzerland plays a relevant role in resilient and international quantum networks, shaping and scaling the future of quantum technologies. In particular, quantum technologies represent a natural extension to leading Swiss sectors such as precision instrumentation, life sciences, and financial services, where they promise opportunities for discovery, innovation and growth.

The **world-class environment** further develops Switzerland's excellent education system and state-of-the-art research and translational infrastructure for quantum, such as accessible advanced labs, engineering and fabrication facilities, and relevant high-performance computing capabilities. It also relies heavily on stable political and economic conditions, efficient and lean regulatory frameworks and access to global markets. These are strongholds of Switzerland.

Building on the SQC strategic recommendations from 2023[6] and providing further guidance for the more technical sections below, this strategy is anchored in the following principles:

Free scientific research

Free scientific research encompasses the right and responsibility of researchers to freely define research questions, propose and develop theories, gather empirical material and employ sound academic research methods to question paradigms, theories and beliefs. This undisputed principle for Switzerland and the international scientific community shall not be interfered with. This does, to a certain extent, restrict the scope of top-down prescriptions for scientific questions in fundamental quantum research.

Entrepreneurship

Switzerland's deep tech landscape – and a significant portion of its economy at large – thrives on the vision and courage of individuals who set up and scale prosperous and profitable SMEs. In several cases this has led to the formation of larger enterprises and corporations with substantial global footprints.[7] Continuing this spirit of innovation and successful scaling is imperative, e.g. by fostering both startups and growing companies – in particular for the still emerging deep tech field of quantum.

Open and liberal market environment

The private sector is the home of customer-oriented and responsible development of industrial, scalable products and services. Correspondingly, key investments in the competitive landscape of an emerging quantum industry are led by entrepreneurs, private companies, investors and deep tech venture capitalists. Traditionally, Switzerland does not rely on an interventionist industry policy but rather focuses on creating favorable framework conditions. Hence, as a publicly funded initiative, the SQI supports meaningful foundations e.g. in the form of translational infrastructures and specific support via competitive calls. However, it does not interfere excessively in market processes or distort private competition. In particular, the SQI does not intend to 'bet on winners' in the corporate race for economic gains.

Responsible innovation

Responsible innovation involves a conscientious and ethical approach to the development and deployment of new technologies and applications. It pays attention to the societal, environmental and ethical implications of innovations throughout the entire process. The goal is to ensure that new technological applications align with shared values, minimize risks, and contribute positively to society while addressing potential concerns and consequences. Like with other technologies – in particular for deep tech – it is impossible to anticipate upfront the full impact of applications from quantum technologies. In light of this fundamental uncertainty and the potentially significant societal impact of emerging quantum applications, the SQC is committed to responsible innovation at national and international levels.

3 The Swiss quantum ecosystem

Switzerland is home to a uniquely fertile environment for science, innovation and technology-based business. This environment is grounded in a world-class education system that excels both in breadth and specialization – from STEM subjects and physics to quantum-specific courses across universities and universities of applied sciences (UAS).[8] The country's research landscape is based on excellent, curiosity-driven scientific work, supported by institutions known for decades of excellence in research and teaching. This has been made possible by an efficient education, research, and innovation (ERI) system, which is responsible for a sound base funding for education and research institutions.

In the fields of basic and applied quantum research, Switzerland's value as a leading international hub is underpinned by the attractive force of Swiss universities. Universities of Applied Sciences and Research and Technology (RTO) institutes play a crucial and increasingly important role in the field of quantum in connecting applied research with industries. Overall, at the time of writing, more than 200 groups are active in the field of quantum science and technology in Switzerland. International collaboration is key to the success of these groups. In a study of quantum publications, 88% of Swiss-authored publications featured an international collaborator – the 2nd highest rate of any country.[9] Numerous bottom-up initiatives and schemes by the Swiss National Science Foundation (SNSF) support the international exchange of researchers, including several bilateral memoranda and agreements with other countries. Whilst the close ties within Europe, exemplified by the Swiss participation in Horizon Europe, are a salient feature, the field of quantum is an endeavor of global proportions.

On these foundations, the Swiss commercial ecosystem in quantum has grown organically through national and international investments and expansions – with institutions and companies having different focus areas.[10] Switzerland's ability to further attract talent, international startups and collaborations is a critical asset to the country's innovation landscape and should be actively fostered through ongoing support measures.

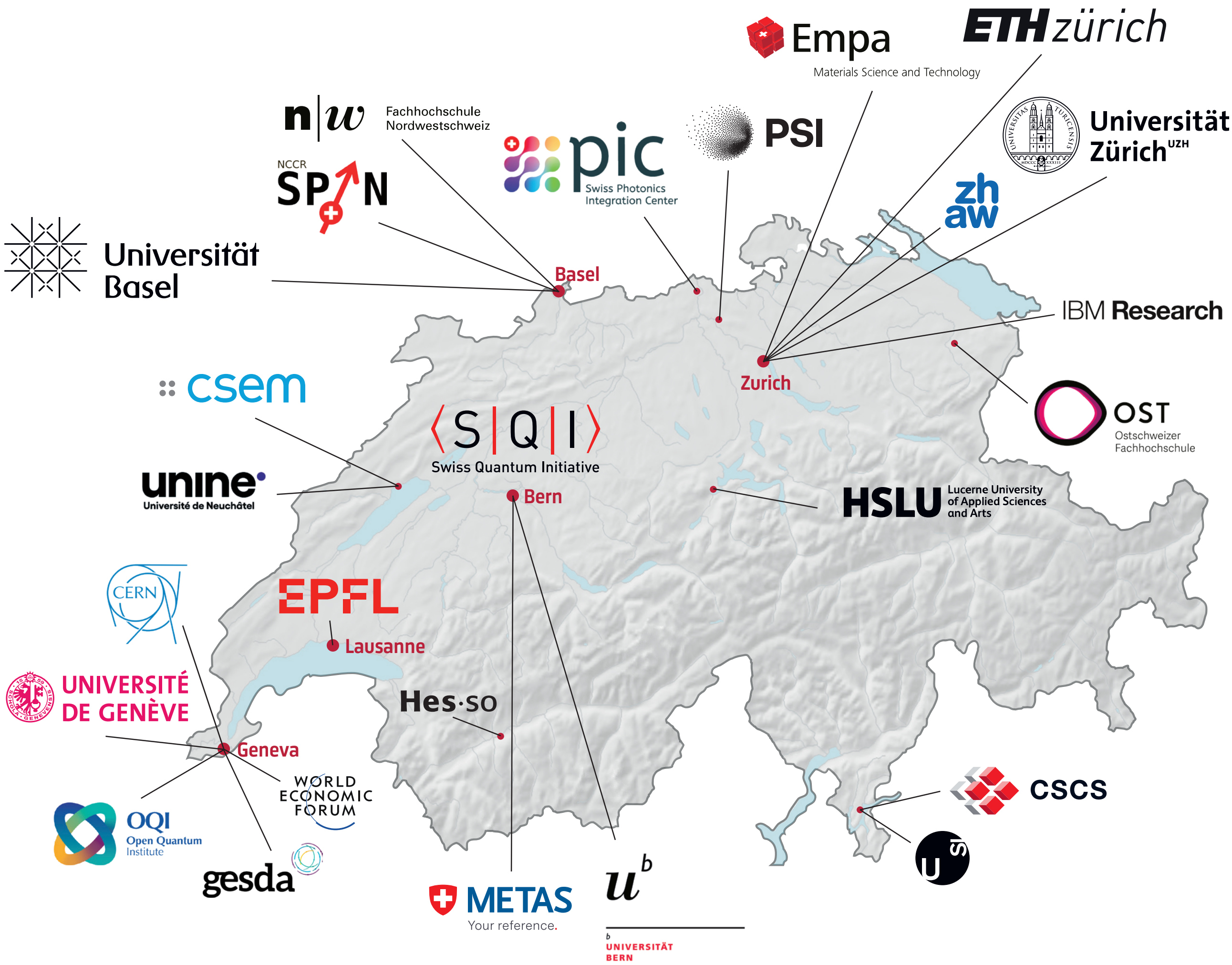
Further, a combination of existing and emerging industry networks, such as Swissphotonics, Swissmem and the Swiss Quantum Industry Network[11] support the ecosystem for quantum applications and enabling technologies. While still at a rather early stage, the Swiss quantum commercial system is highly attractive as a hub for commercial investment from around the globe.[C]

Also key to Switzerland's ecosystem is the multitude of international and multilateral institutions. The Open Quantum Institute, hosted at CERN and launched through the Geneva Science and Diplomacy Anticipator (GESDA), tackles issues of broad and equitable access to quantum, applications for humanity, and effective multilateral governance in quantum to ensure the greatest good for our quantum future. The World Economic Forum (WEF), meanwhile, engages global companies in preparing for the quantum economy.

The breadth of research and innovation topics pursued and the associated skill base is one of the key strengths of Switzerland. Relative to the high number of internationally renowned Swiss quantum research groups and their output, there are still relatively few startups and in particular scale-ups.[10] This can be linked, in part, to the government's non-interventionist approach: it does not engage in selective industrial policy or provide direct subsidies to individual companies. Scaling efforts in Switzerland thus require substantial private investment. Furthermore, a lack of industrial-scale fabrication capabilities, for example for chips or cryogenics, exemplifies Switzerland's reliance on international partnerships and supply chains.

C For a periodically updated overview including private organizations visit the Swissnex website.[10]

Figure 2: Schematic of the Swiss quantum landscape[D]
(showing public and non-profit organizations and accredited research institutions).



Source: commons.wikimedia.org/wiki/File: Switzerland_topographic.png

D For a periodically updated overview including private organizations visit Project Quantum by Swissnex.[10]

4 Strategic direction

Figure 3: Strategic goals: overview

4.1 Position Switzerland as an **international hub** for quantum science and innovation

4.2 Foster world-leading **interdisciplinary fundamental and applied research**	4.3 Strengthen and extend **translational infrastructures, platforms and engineering services**	4.4 Accelerate **scaling and commercialization** between academia, startups, SMEs and enterprises

4.5 Further strengthen **education and training** for curious and competent scholars and experts

4.1 Switzerland: an international hub for quantum

Switzerland relies on international openness and collaboration for the success of its quantum ecosystem. This positioning should be maintained, even as the multipolar global quantum landscape shows signs of restrictions on selected exports, on research collaborations in 'strategic' areas, and even in some cases on talent flows.

The Swiss quantum ecosystem remains focused on open and multi-level collaborations among like-minded countries pursuing quantum technologies on the principles of democratic governance and market competition. It does so with its own approach. Several countries are investing heavily in national quantum programs and selected national champions which feeds the narrative of a quantum 'race' between countries – with significant hype.[12] The Swiss ecosystem relies largely on the excellence of its education system, infrastructures and bottom-up scientific and innovation pipelines, with comparatively light-handed 'on-top' national coordination. These structures are designed to create a long-term sustainable environment of excellence and a basis for Switzerland to pursue the path to a quantum-enabled economy and society.

Aspirations towards autonomy or even independence for Switzerland in the deep tech area of quantum technology would be misguided. Cutting-edge research, the development of highly complex systems (with corresponding supply chains) and, ultimately, commercial success in this field require international cooperation and sufficiently open markets. To this end, Switzerland actively participates in international quantum programs and partnerships while ensuring strategic sovereignty.

The Swiss quantum ecosystem aims to remain as open as possible, and continues, for example, to promote global talent mobility. At the same time, it is recognized that the greatest potential for collaboration in critical areas lies with like-minded countries that share similar economic and political principles. This includes, at its core, EU countries and the countries active in the Multilateral Dialogue on Quantum[13] with shared interests and complementary capabilities. Switzerland leans on its historic reputation of neutrality to insist on the greatest levels of scientific openness and transparency achievable within the confines of the current geopolitical moment,[14] while generally allowing for autonomy and flexibility through the bottom-up initiative of its actors. Numerous bottom-up initiatives and SNSF general schemes support the international exchange of researchers, including several bilateral memoranda and agreements.

4.2 Interdisciplinary fundamental and applied research

In many respects, the field of quantum is still at a point where exploration of diverse approaches could lead to game-changing breakthroughs. Consequently, continuing interdisciplinary fundamental and applied research is imperative.

The importance of fundamental research goes beyond providing a base for practical applications: it addresses foundational scientific questions and deepens our understanding of nature and the universe at large. Even when not directly aimed at commercial innovation, such fundamental research is vital for intellectual progress and the advancement of science itself. The field of quantum holds promising potential to enable new pathways and instruments to help tackle some of the hardest scientific questions at hand.[15, 16] The value of quantum science for science cannot be overstated.

Switzerland's strength in quantum research has been built on long-term strategic investments. Since 2001, the Swiss National Science Foundation has funded major NCCRs focused on quantum topics. These include Nanoscale Science, Quantum Photonics, Quantum Science and Technology, and the ongoing NCCR SPIN. Each of these programs, typically spanning over a decade with an overall funding of around CHF 150 million,[5] has helped build a robust national research infrastructure and trained a generation of highly skilled quantum scientists. The continuation and interdisciplinary evolution of such long-term research programs is vital to support bottom-up research approaches, creating space for curiosity-driven innovation that can lead to unexpected breakthroughs and new research directions, like the quantum secure transmission of data through the Swisscom network,[17] room temperature quantum cascade lasers[17] and self-oscillating topological pumps.[18]

Switzerland's reputation for excellence in basic and applied research remains a pillar for its future global attractiveness. It draws international talent, secures participation in large-scale research consortia, and positions Swiss innovations as trusted, high-quality products on the global market. Swiss laboratories have become key players in the European Union's Quantum Flagship, participating in 11 of the first 21 funded projects during the ramp-up phase 2018–2022.[19]

4.3 Translational infrastructures, platforms and engineering services

Fit-for-purpose infrastructures, platforms and corresponding shared services have a critical influence on innovation in the field of quantum, in particular for mid- to higher TRLs. In this context, it should be underlined that infrastructures, platforms and shared services only deliver their full potential when deployed with strong quantum engineering teams on an ongoing basis to serve the innovation process. While the development of quantum technologies is hardware intensive, it is the people who ultimately make the difference.

These capabilities are particularly relevant in those maturity levels (TRL 5 to 8) that are currently not fully covered by universities, universities of applied sciences or emerging industrial players. Organizations like the Swiss Center for Electronics and Microtechnology (CSEM) and the Paul Scherrer Institute (PSI) host research facilities in combination with translational infrastructures, platforms and test environments, for example for photonic or superconducting quantum architectures, cryogenic subsystems or quantum sensor technologies. These types of organizations and the infrastructures and platforms they host play a key role for the future of quantum in Switzerland.

Spin-offs, startups and SMEs in quantum currently still lack sufficiently structured and application-oriented access to relevant infrastructures needed to translate their developments to higher maturity levels. Several of these companies must therefore either continue prototyping or development in academic laboratories, or move abroad – often at great expense in terms of time and capital. Hence, a top priority for Switzerland is the build-out of quantum-specific translational infrastructures (including but not limited to clean rooms, cryogenic technology, photonic testbeds, etc.). Existing infrastructures can, of course, be made accessible to startups and SMEs as part of these efforts. In the overall still early state of developments in the field, the focus for the Swiss quantum ecosystem continues to be on both: integrated quantum systems for end-user applications as well as a broad set of enabling technologies and individual components.

4.4 Applications, scaling and commercialization

By the first quarter of 2024, 78 patent families related to quantum technologies had been filed in Switzerland. A significant share of these originated from university research, often through spin-offs.[20] These spin-offs pursue the goal of transforming scientific findings into commercially viable products or services – a critical building block for technology-driven value creation. However, an international comparison shows that many countries support their research excellence with targeted measures for economic scaling – for example through state-funded test infrastructures, specific funding programs for quantum startups or national coordination offices.[21]

Transforming scientific excellence into viable, marketable business models remains a systemic challenge globally – and a priority for the Swiss quantum ecosystem. The so-called «valley of death» between basic research and industrial scaling is particularly pronounced in the deep tech sector of quantum due to long development cycles, high capital intensity and complex regulatory requirements.[22]

There are already several companies active in the field,[10] either as pure-play quantum companies for systems or components, or as high-tech firms who have a vested interest in one of their product or technology lines. The outlook for both types of players is promising, especially for SMEs developing new specialized technologies.

International experiences show that structured commercialization architectures contribute significantly to increasing the probability of transfer and scaling. This includes functions such as technology transfer, IP management, mid- to later stage innovation support for scaling efforts and industry partnerships.[23] As a top priority, this requires technology-adequate financing instruments, translational infrastructure (e.g. test beds, IP platforms), fostering early adoption in the private and public sectors and the provision of entrepreneurial expertise.

The development of quantum technologies is capital-intensive, risky and associated with long development times. For quantum hardware, it often takes more than seven years for the first marketable applications to emerge. During this phase, high investments are often made without any clear short-term returns. This environment is not very attractive for traditional venture capitalists because their business model is generally based on a rapid exit – i.e. the sale of a startup or its shares – within five to seven years. In order to systematically address this financing gap in Switzerland, international organizations such as the OECD recommend, as a top priority, the establishment of state-supported deep tech funds that are designed for longer-term technology development.[24] Additional levers should also be created to mobilize further private investments. This applies in particular to matching funds (public funds doubling private investments), tax incentives for high-risk technology investments and the review of regulatory hurdles, such as the investment limits for pension funds (BVV2).[24, 25] This presents Switzerland with a double opportunity: not only can it translate its scientific strengths into economic progress, it can also attract investment and further expand its role as an international hub for quantum.

4.5 Education and training

Large parts of the field of quantum rely on highly advanced technologies to build complex instruments and integrated systems. None of this is possible without well trained talent to develop, enhance and use these technologies. While, globally, there is a shortage for skilled quantum talent,[26] Switzerland already has an excellent and diverse education and training system in place that fosters curious minds in scientific and applied research and teaches innovation on all levels.[8]

One of Switzerland's strengths lies in its dual vocational education and training (VET) system.[2] Around two-thirds of young people complete an apprenticeship that combines practical work in a company with classroom instruction at a vocational school. Apprenticeships permeate many sectors of the economy, including in quantum, where they work as technicians in physics and applied research laboratories or at engineering firms. This dual system enables people to develop practical and theoretical knowledge, helping to drive innovation and train innovative minds.

The Swiss educational system is flexible in encouraging the exploration of different paths and fields. University study is open to graduates from the Gymnasium (preparatory high school), but also to graduates of apprenticeships. This ensures permeability and social mobility, leading to a diverse workforce. Research universities drive cutting-edge science, while universities of applied sciences focus on practical innovation and collaborate closely with industry on emerging applications. The education stays aligned with current and future labor market needs, while also creating a dynamic environment for innovation and technology transfer. To stay competitive the opportunities and challenges of quantum technologies must be incorporated into the system more rapidly. Education of quantum technologies needs to be implemented early on to motivate and enable quantum careers.

So far, quantum experts have mostly come through PhD programs to the job market. While they have deep specialization and research experience, it is a lengthy and often exclusive path. Swiss universities have already started to adapt to the maturing field of quantum technologies by implementing designated Masters in quantum engineering degrees. Some quantum companies engage with apprentices or student researchers, creating real-world learning opportunities at the frontier of quantum technologies. However, current vocational training does not yet cover many quantum-relevant technical skill areas like quantum optics, cryogenics or microwave technologies. Further, universities of applied sciences should play a bigger role by offering specific applied training in areas relevant for quantum technologies. These steps are crucial to ensure a steady and adaptive stream of well-trained talent, enabling individuals to contribute meaningfully to the quantum workforce without necessarily holding a PhD.[27]

5 Positioning and direction per technical area

Four application-oriented areas within the field of quantum are at the core of this strategy for the Swiss quantum ecosystem. Notwithstanding the importance of cross-sectional topics like materials science as well as important purely scientific questions, the main areas of action – and expected outcomes – in the field of quantum are summarized by 'to communicate, to compute, to simulate and to measure.' It should be noted that this strategy only addresses technologies and applications that directly build on quantum-mechanical effects.[D]

5.1 Quantum communication

Quantum communication is the use of quantum mechanical principles – such as superposition, entanglement, and the no-cloning theorem – to transfer quantum states from one location to another in order to e.g. transmit information between parties. Unlike classical communication, quantum communication can enable fundamentally new capabilities, such as unbreakable encryption through quantum key distribution (QKD), ultra-sensitive detection of eavesdropping, cryptographic applications, and the potential for future quantum networks that link quantum computers or sensors over long distances.

In most cases, secure communication relies on cryptographic systems. However, a future, sufficiently powerful quantum computer could leave the most widely used of today's cryptographic systems insecure,[28] thus requiring counteraction. As a short-term step to protect sensitive data, so-called 'quantum safe' post quantum cryptography (PQC) protocols need to be implemented. In parallel and with increasing technological maturity, further implementation of secure quantum communication for highly sensitive information via quantum key distribution (QKD) methods is advisable.

At the same time, quantum technology enables novel cryptographic applications, such as random number generation, copy protection or distributed computing. Future quantum networks are expected to maximize the benefits of quantum computers: the ability to send a computational task to a distant quantum cloud computer without anybody – not even the computer itself – being able to learn the task ('blind' computing) and the possibility to connect quantum computers, atomic clocks or optical telescopes for superior computational performance and time standards.

Swiss research has led pioneering work in quantum cryptography, photonic integration, and entanglement distribution, establishing a solid foundation for future quantum internet architectures. This academic excellence, combined with strong innovation pipelines and industry partnerships, forms the foundation for Switzerland to remain at the forefront of quantum networking technologies.

While components and sub-systems like QKD, single-photon detectors, and quantum random number generators (QRNGs) have already reached high TRLs and are commercially deployed, these represent only the initial layer of what will evolve into fully quantum-enabled networks. The next phase of development aims to transcend current limitations by creating integrated quantum repeaters and processing-capable network nodes, essential for achieving long-range quantum entanglement and enabling applications like blind quantum computing and distributed quantum sensors.

To enable this, a critical focus is on on-chip integration and photonic circuit scalability, paving the way for compact, robust and manufacturable quantum networking hardware. This technological leap will be complemented by the development of interoperable quantum communication protocols and the establishment of large-scale, heterogeneous quantum networks that combine various physical platforms and technologies into cohesive systems.

In communication security, Swiss companies and government institutions have so far been rather cautious in adopting novel technology such as quantum cryptography. Additionally, unlike other countries or regions (EU, UK, Korea, China, Japan, Singapore, etc.) which are setting up large quantum key distribution networks, Switzerland has no such provision yet. For commercial actors, the costs of creating such a network, initially for testing, learning and ultimately for actual use, is too high. Switzerland is therefore in danger of not further developing this technology and the market that it will eventually serve, fueling the risk of falling behind.

Building a real-world Swiss quantum communication testbed and network is of critical importance. In a first

D In technical terms: the existence of incompatible physical observables as quantified by h-bar.

phase, this would allow testing and improving quantum network technology, and learning how to deploy and use it. In the future, such a platform could become the seed for a Swiss-wide quantum network, developed by Swiss companies and used by Swiss government as well as public and private institutions, ultimately strengthening the security and resilience of Swiss critical infrastructure from the financial system to energy network. Such a platform is needed for sovereignty in the secure communication sector regardless of developments in other countries, and would also allow Switzerland to link with the EuroQCI.[23]

5.2 Quantum computing

Quantum computing, as classical computing, has three main components: hardware, algorithms and software, enabling compilation of quantum programs onto a set of logic gates each operating on a small number of quantum bits (qubits). On the hardware side, the challenge is to engineer highly complex devices which offer a high level of control over large numbers of high-quality qubits. Multiple approaches, including but not limited to trapped-ions, superconducting circuits, spins in solids, photons and neutral atoms are being explored, with the leading systems today featuring hundreds of qubits and gate success probabilities as high as 99.9%. Further scaling and improvements in accuracy are required towards reliable fault-tolerant performance. A universal quantum computer should come equipped with a programmable set of gates that can be used to implement any quantum computation, suitably compiled. The applications goal is to design quantum algorithms that efficiently solve real-world problems and compile such algorithms into sequences of gates that can be executed on a given quantum device. Quantum hardware and software combined must demonstrate a clear advantage for end users over classical approaches.

The field of quantum computing has boomed over the past decade, based on rapid technological and scientific advances. Governments as well as industry leaders worldwide have been betting heavily on the promises of this new technology. Going beyond currently demonstrated capabilities, a pervasive 'fear of missing out' has led to speculative investment, driving the field forward. This situation has driven complex and competitive dynamics involving academia, industry and investors as well as governmental entities.

While the concept of quantum computing opens radically new and promising avenues to solving certain mathematical problems, it is not yet a mature technology, and critical challenges remain. As of now, neither quantum hardware capable of large-scale fault-tolerant quantum computation, nor any end-to-end commercially successful application thereof, has been demonstrated. On the hardware side 100 qubit systems have been realized across multiple platforms including trapped-ions, superconducting circuits, and neutral atoms, each of which have been able to demonstrate complex circuits beyond the capabilities of simulation on classical machines (for specific mathematical problems). Useful quantum computers will, however, likely require more than 100,000 physical qubits, in order to utilize error correction to reliably store at least 1,000 suitably high performance 'logical' (fault-tolerant) qubits. Although the past years have seen many impressive demonstrations of error correction, it is still not implemented at high enough quality, and only modest performance gains have been seen for a few encoded logical qubits. Resulting error probabilities are on the order of 10^{-3}, while levels of 10^{-10} are expected to be required for real computations.

On the application side, there are two main challenges. Firstly, when large error-corrected quantum devices are expected to become available, what will these devices be used for? Long lists of candidate applications are being discussed. Yet, none of these have shown a conclusive demonstration that the quantum device will provide a concrete and substantial end-to-end advantage. Secondly, in the shorter run, where devices with thousands of high-quality, yet not fully fault-tolerant qubits, become available: what benchmarks, classical-quantum hybrid approaches, mitigation and improvement techniques will be available? In this regime, any application is expected to be ad hoc, i.e. hardware dependent (e.g. quantum simulation), heuristic (no provable guarantees) and possibly inconclusive (impossible to certify correctness or quality of the solution). This regime is expected to be dominant for at least the next five to ten years. Actively fostering this era of increasingly useful but not-yet-perfect quantum computing is crucial for the future of the field.

As systems increasingly mature, it becomes unreasonable to scale and operate them in university environments. Throughout, the interplay between academia and industry is essential. Switzerland has the potential to provide a rich ecosystem that can attract quantum hardware and software companies at various stages of development and on various levels of the hardware-software stack (regardless of whether this leads, short-term, to the in-house development of a full-scale quantum computer). While developing and building a quantum device is one thing, operating it – and, most importantly, demonstrating its utility – is another.

In the long run, given the core characteristics of quantum algorithms and their radical novelty compared to classical approaches, the range of practical applications is expected to be far-reaching. Yet, at the time of writing, it is not possible to rigorously sketch out the set of useful applications over the next 10 to 15 years. Although still in development, quantum computing (primarily in the form of hybrid quantum-classical algorithms) is expected to deliver an increasing number of practical benefits to various industries, including the life sciences and financial services. In the field of life sciences, it is set to improve the modeling of molecules and proteins, accelerating drug discovery and facilitating the more effective use of genomic data for personalized medicine. In financial services, it could among other uses improve fraud detection and risk modeling by solving certain mathematical problems far better than classical approaches.

To advance the field and further strengthen Switzerland's position, significant research and fundamental engineering efforts are needed, including scaling of systems and improvements in the precision of control. Investments in a base of engineering, state-of-the-art tools and testbeds accessible to researchers and companies are required across relevant enabling technologies, including but not limited to low-noise electronics, clean-room fabrication, cryogenics and photonics. This is a long-range investment, which also relates to the other three technical areas in this strategy.

5.3 Quantum simulation

Quantum simulation is a technique that uses highly controlled quantum many-body systems to reproduce a specific Hamiltonian – the mathematical model of a quantum system – in the laboratory. This allows researchers and innovators to study complex quantum behavior experimentally. Around 30 years ago, numerical simulations became a key scientific tool, helping to analyze systems too complex for analytical solutions. Quantum simulation follows a similar logic: it can provide insights where numerical methods fall short. By mimicking the behavior of target quantum systems, experiments can reveal information that is otherwise inaccessible. This approach may lead to the discovery of advanced materials for electronics, the design of novel pharmaceuticals, and the simulation of fundamental particle interactions – paving the way towards breakthroughs in materials, chemistry and physics.

The first companies now offer access to their quantum simulators, signaling growing commercial interest and adoption. As quantum technologies continue to evolve, quantum simulation is expected to be a key driver of innovation and discovery. The components, tools and techniques used in quantum simulation often align with those of quantum computing, fostering synergy between the two areas and accelerating progress in both.

Quantum simulation is also emerging as a powerful driver of artificial intelligence (AI) technology, particularly as a source of high-quality data for training AI systems, promising near-term application. Continuous advances in quantum simulation experiments have made it possible to generate data from complex quantum many-body systems that AI can subsequently learn from. Research, with key contributions from Swiss theoretical physicists, has shown that AI can in principle replicate much of the behavior of strongly interacting quantum systems, which are central to some of the most challenging unsolved problems in physics and chemistry. This blending of quantum simulation with AI not only enhances our capabilities to describe quantum phenomena but also opens new commercial opportunities. The scalability of AI models trained on quantum data means that the resulting software can be distributed widely, enabling researchers around the world to tackle intricate quantum problems with greater efficiency. This synergy is expected to accelerate scientific discovery and innovation across disciplines.

Fostering the field of quantum simulation is a core component of this quantum strategy, including the establishment of a larger-scale national quantum simulation facility, offering access to a broad user base. Options may include that private companies offer such a service via web interface. Further mechanisms need to be established to support the development of key enabling technologies for quantum simulation like control electronics, software, and advanced optical systems. For example, there is a unique opportunity to develop a software platform, akin to an operating system, for quantum simulations. With regards to optical technologies, the generation, control, and shaping of laser fields, including precision and nano-optics, play a crucial role. To accelerate progress and support private-sector growth, it is recommended that resources directed towards research consortia can be used to outsource technological development to companies, following models used in space science.

5.4 Quantum sensing and metrology

Quantum sensing leverages quantum mechanical properties, such as superposition, entanglement and coherence to achieve unprecedented precision in measuring quantities including magnetic fields, temperature, acceleration, and time. These sensors detect minute changes in operational regimes where traditional sensors often fail, achieving, e.g., higher sensitivity, robustness, resolution or bandwidth than their classical counterparts. Furthermore, because their response is often determined by fundamental constants of nature only, many quantum sensors are inherently self-calibrating, thereby removing the need for costly, regular calibration. Therefore, in some cases, they can even serve as primary measurement standards themselves.

Across all quantum technologies, quantum sensing represents one of the technologically most mature pillars, with a plethora of highly relevant applications already being pursued. A rich variety of powerful quantum sensing platforms have thus far been established (solid-state spins, cold-atom gravimeters, superconducting SQUIDs, chip-scale atomic clocks, trapped-ion clocks, etc.), with several having already reached a TRL of six to eight. Commercial quantum sensing devices are already being deployed in semiconductor process control, medical imaging, environmental monitoring, navigation, material science, and security-critical roles such as GPS-independent navigation and quantum imaging for defense. Quantum sensing devices thereby already solve pressing needs of industries outside the quantum sector,[29] where they show significant growth potential across a wide range of use cases, a breadth that renders this technology robust to weather uncertainties and market variability.

Switzerland, with its longstanding heritage in precision measurement and instrument making, is well positioned to be a global leader in the field of quantum sensing – poised to become a key strategic asset in Switzerland's future quantum industry. Our country hosts world-leading research groups and startups in quantum sensing, all of which pioneer novel sensing technologies. Switzerland's economic backbone includes many successful SMEs that are ideally suited for adopting and scaling quantum sensing solutions. These companies often exploit niche markets where unique know-how and high-precision products allow for the necessary high margins. This fragmented market also offers an opportunity to grow a robust, broadly anchored industry.

While a significant base of capabilities for quantum sensing and metrology is already in place within Switzerland, further efforts and public and private investments into scaling and commercialization of technologies is required. A culture of early adoption should be pursued more boldly in this particular technical area, both in Switzerland and on the international stage.

6 Recommendations and outlook

To ensure Switzerland maintains and strengthens its position as a global leader in quantum science and technology, bold and coordinated efforts encompassing academia, industry and policy making are essential. Below are the key recommendations and strategic priorities that can drive Switzerland's quantum ecosystem forward.

Figure 4: Strategic goals and high-level direction ('flavor' of this strategy)

Switzerland as an international hub for quantum	**'More than ever.'**
Interdisciplinary fundamental and applied research	**'Continue. Curiosity-driven excellence.'**
Translational infrastructures, platforms and engineering services	**'Focus. Develop. Invest.'**
Scaling and commercialization	**'Bolder and faster. Invest.'**
Education and training	**'The underlying stronghold (much broader than physics PhDs).'**

Switzerland as an international hub for quantum

Switzerland's quantum ecosystem thrives on openness, collaboration, and academic excellence. It partners with like-minded ecosystems and leading international players to advance shared progress.

	Key areas for action
Dialogue and partnering	– Maintain the highest level of collaboration with partners in Europe including the integration of Swiss institutions into EU programs like Horizon Europe. Actively liaise with the EU towards the Quantum Act [29]. – Strengthen strategic bilateral ties with other advanced quantum programs and institutions. – Actively support and shape multilateral efforts and forums on quantum, in alignment with international bodies and associations.
International promotion	– Promote the Swiss quantum ecosystem internationally with science, innovation and diplomacy: 'L'esprit de Genève' (the Geneva spirit). – Further extend the 'Made in Switzerland' label to quantum technologies to enhance global trust and economic value; 'Quantum Switzerland' (working title),
Talent attraction	– Create a 'soft landing program' for foreign startups, SMEs, institutions and individual students and professionals e.g. for relevant networking opportunities, simplified visa processes, and platform or infrastructure access.

Interdisciplinary fundamental and applied research

Switzerland's long-term investments and achievements in quantum research have built a world-leading academic base that drives both discovery and innovation. These efforts strengthen its global reputation, attract top talent, and anchor Switzerland as a trusted partner in international quantum science.

	Key areas for action
Advancing research	– Tackle major scientific questions that · enable pathways toward application-ready quantum technologies, and use quantum technologies to help solve some of the toughest scientific questions in nature. · Expand and sustain funding for academic excellence in both fundamental and applied quantum research as well as quantum engineering – across all four technical areas and a broad range of physical approaches to implementing quantum technology.
Strengthening engineering leadership	– Invest in and demonstrate leadership in quantum technology engineering, with substantial contributions to next-generation processes, devices and systems. – Build out quantum engineering capabilities required by fundamental and applied quantum research.
Interdisciplinary collaboration	– Foster interdisciplinary research and innovation projects, in particular relating to quantum physics with computer sciences, engineering, materials science, chemistry, biology, life sciences, and space research and technologies. – Foster interdisciplinary collaboration through shared platforms.

Translational infrastructures, platforms and engineering services

Switzerland's quantum innovation depends on strong, fit-for-purpose infrastructures and engineering platforms that bridge the gap between research and industry. Expanding translational facilities and access, in particular for startups and SMEs, is essential to advance technologies from prototype to application and strengthen Switzerland's quantum ecosystem.

	Key areas for action
Translational infrastructures	– Extend and augment translational infrastructures and platforms between academia and industry – specifically for applied quantum technologies: · Build out a national quantum communication platform towards a joint quantum network for industry and academia, interconnected with partner countries. · Recognize and support evolving quantum computing centers of expertise across Switzerland as part of a coordinated national framework. · Establish a larger-scale national quantum simulation facility, offering access to a broad user base (in close alignment with quantum computing centers of expertise). · Create dedicated quantum sensing centers of expertise for early adoption, testing, and demonstration of Swiss quantum sensors.
Engineering and shared services	– Build and extend national engineering centers of expertise to offer relevant shared services to academia and Swiss-based industries, including but not limited to cryogenic, nanofabrication and low-noise electronics services. – Support independent testing and certification bodies to ensure credibility and evolving standards where applicable.
Coordination and collaboration	– Encourage and fund collaboration via seed grants, vouchers, and other channels to encourage cross-institutional and international usage of shared platforms. – Develop and maintain a national roadmap for quantum-specific platform and infrastructure development – aligned with industrial needs and academic strengths.

Scaling and commercialization

Switzerland's quantum ecosystem is particularly strong in research and spin-off activity but faces challenges in translating scientific excellence into scalable commercial success. Long development cycles and high capital needs make bridging the gap between innovation and market application a key priority.

	Key areas for action
TRL enhancement and scaling	– Provide mid- and later-stage innovation funding and entrepreneurial support in quantum technologies to nurture new ventures. – Design and establish a state-supported deep tech fund for long-term technology developments, including quantum technologies. Derisk and encourage private investments.
Technology transfer and commercialization	– Craft a culture of early adopters including public sector customers as well as partially or fully state-owned organizations. – Simplify administrative and regulatory hurdles for startups and SMEs including onboarding of international staff. – Foster activities towards increasing international standardization in the field of quantum – as a catalyst, not a blocker for the field.
International partnerships	– Further attract and work with international companies to continue and extend presence in quantum technologies in Switzerland. – Pursue competitive trade conditions and engagements for startups and companies established in Switzerland.

Education and training

Switzerland's blend of academic excellence, vocational training and talent mobility provides a strong base for quantum innovation. To remain competitive, relevant skills for quantum technologies (not just physics) should be integrated earlier and more widely across education and training pathways.

	Key areas for action
Developing talent for quantum	– Maintain and evolve a world-class learning environment for students of all ages, embedded in curiosity-driven quantum research and innovation. – Sustain high levels of funding and support for STEM education.
Bridging academia and industry	– Foster targeted quantum engineering programs and workforce tracks including hands-on technical components. – Further establish industry to PhD tracks with stipends to encourage application-oriented doctoral research.
Quantum awareness and outreach	– Offer outreach and education programs for all generations, including at the high school level, to inspire future quantum talent and societal engagement.

Figure 5: Top translational priorities going forward (high-level selection)

1. Extend and augment **translational infrastructures, platforms and shared services** between academia and industries – specific for applied quantum technologies.

2. Ensure financing of **scaling up** and craft a culture of **early adopters**.

3. Design and establish a **state-supported deep tech fund** for long-term technology developments – including quantum technologies. Encourage and **derisk private investments**.

In summary and looking ahead, Switzerland is uniquely positioned to lead in specific quantum domains – such as quantum sensing and precision instrumentation – by leveraging its research excellence, industrial strengths and high-quality engineering. However, seizing this opportunity will require coordinated efforts: bold public and private investments with a reasonable degree of patience, strategic infrastructure development, and stronger integration between research and industry.

While this document does not aim to provide a comprehensive implementation plan, to drive these top priorities over the next 6–8 years requires attention to key frameworks:

1. Based on analysis of SQI calls for ideas and of recent project proposals,[31] the required investments into quantum-specific translational infrastructures, platforms and shared services are on the order of CHF 200 to 300 million. The strategic fit with selected host institutions needs to be assured as well as mid- to longer-term operational plans. Public-private matching funds (roughly 1:1) provide for a meaningful base, which can stimulate both scientific discoveries and contributions to application innovation pipelines. These public-private investments are a key contribution towards ensuring the strategic sovereignty of Switzerland in the field of quantum.

2. Given the current state of the quantum ecosystem and number of spin-offs and startups in recent years, around ten or more smaller Swiss-based companies should scale up over the next four to six years. Correspondingly, public innovation funding is most effectively deployed via accelerator-like instruments.[32, 33] Significant scaling of technologies and corresponding companies in the field of quantum (i.e. moving from series A to series B funding – and beyond), often involves financial volumes of several CHF 10 million to CHF 100 million per case. The majority of funding will come from private capital, but derisking private investments with complementary public support is recommended and, in light of international competition, crucial.

3. Similar to pathways already implemented in other countries or via organizations,[34, 35, 36] a state-supported deep tech fund is highly recommended for Switzerland – as an additional and bold step to boost deep tech investments with mid- to long-term benefits for the Swiss economy. Current plans and estimates[37] suggest enabling multi-billion CHF investment levels over the next decade. A cross-thematic approach, including but not limited to quantum technologies, seems adequate to ensure sufficiently broad and large investment portfolios, balancing of risks and attractive returns for investors.

7 Acknowledgements and signatures

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SCNAT – Network of knowledge for the benefit of society

The **Swiss Academy of Sciences (SCNAT)** works at regional, national and international level for the future science and society. It strengthens the awareness for the sciences as a central pillar of cultural and economic development. The breadth of its support makes it a representative partner for politics. The SCNAT links the sciences, provides expertise, promotes the dialogue between science and society, identifies and evaluates scientific developments and lays the foundation for the next generation of natural scientists. It is part of the association of the Swiss Academies of Arts and Sciences.

The **Swiss Quantum Initiative (SQI)** is the federal quantum initiative to strengthen Switzerland's leading position in the field of quantum science and technology. It was launched in 2022 and is hosted by the Swiss Academy of Sciences (SCNAT). The initiative operates under a mandate by the State Secretariat of Education, Research and Innovation (SERI) and its implementation involves three main institutions: the Swiss National Science Foundation, Innosuisse and SCNAT.

The **Swiss Quantum Commission (SQC)** is the steering group of the SQI and its members are elected ad personam by the SCNAT Executive Board. The purpose of the SQC is to strengthen and further develop Switzerland's leading position in the field of quantum technology, from basic research to application. It brings together the expertise of research, innovation and application in the field of quantum in Switzerland. As a Swiss 'Miliz' group, the commission usually meets once a month under the rules of prodedure of SCNAT. The State Secretariat of Education, Research and Innovation, the Swiss National Science Foundation, Innosuisse and the SCNAT Executive Board are each represented by one delegate.