Business Roadmap

for BusinessQ

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1. Introduction

The long-term success of the quantum industry in any country requires:

- a fertile business ecosystem that develops and deploys critical technologies;
- access to infrastructure where new technologies can be tested and developed; and
- an ability to meet the growing worldwide demand for quantum solutions.

Such an ecosystem can broaden the impact of quantum technology in industry, through co-operation and discussion with enabling technology providers and end-user companies and enable Finland to develop a sustainable quantum supply chain for critical technologies. This is of course just one pillar, a skilled base of researchers and engineers versed in quantum technology and high-quality research are also crucial in quantum technology as in any emerging high tech business areas.

InstituteQ promotes Quantum Technologies in Finland and it consists of three parts BusinessQ (focusing on business, i.e., development, productization and commercialisation), EduQ (focusing on education) and ResQ (focusing on research). InstituteQ is currently in process of creating the Finnish National Quantum Agenda and uses this document as one source of input.

Over the several decades, special expertise and excellent networks have accumulated into Finland related to quantum technologies, radio-frequency electronics and ultra-low temperature physics. This gives opportunities for new deep-tech companies whose business is based on recent breakthroughs in science and technology, offering unique and disruptive solutions to global problems. The products and solutions developed by deep-tech companies could be used to speed up research and provide better educational tools. Wider industrial and societal effects of quantum technology are yet to be realized.

This paper focuses on quantum hardware related aspects due to the current BusinessQ (later BQ) composition and strong research background in hardware. It is important to note that also the quantum software business is emerging and it presents plenty of opportunities for the Finnish companies as well. Software industry needs tools and research to be able to develop efficient solutions to be ready for immediate utilization in the beginning of the quantum-advantage era.

The increase of the number of SMEs engaging in Quantum Technologies is related to how attractive a place Finland is to start a business, make it grow and scale up in the international markets. Actions that help SMEs and academia and research organizations to develop shared and proprietary infrastructures, capacity-building through public-private partnerships and support, improve market access and improve access to financing are important. To bring results, this kind of agenda must be driven jointly by national actions and strong commitment by the Finnish government and quantum companies.

For businesses to succeed, stakeholders need a shared understanding of the big picture and willingness to contribute. This paper presents the BQ's business roadmap with existing and planned partnerships across different organizations, visualize the major objectives and illustrate initiatives and timelines. It gives a long view of where the Finnish Quantum Business Ecosystem is going and how it will get there.

The business growth of each individual company depends on many factors, e.g., business owner vision, culture and employee engagement, the external environment and funding. This paper is not covering these company-level issues but provides a generic view inspired by discussions with the companies in the BusinessQ ecosystem and published roadmaps. Another factor necessary for the success of quantum SMEs is access to infrastructure and corresponding services that dramatically reduces the cost of product development.

Here we present implementation of the roadmap and suggested actions as potential operations and services. BQ is a natural actor here but it needs resources to implement the roadmap. While this is important to understand, the funding and business model of BQ is not discussed in this document.

The editor of the document is Olli Nurmi for VTT, principal scientist in Quantum Software and Algorithms. The first version was written in a core group consisting of two additional experts, Jukka Nurminen (University of Helsinki) and Ilkka Tittonen (Aalto University). Contributions were also gathered from active BQ companies (QuantrolOx, IQM, CSC, IBM and Unitaryzerospace). The final version was created in December 2022.

2. Business growth enablers

Quantum technology constitutes a promising and rapidly growing industrial sector. Globally, an increasing number of companies are developing solutions that leverage the fundamental properties of quantum mechanics. The sector's growth is fuelled both by governments and investors, and billions of euros in funding and investment have already been deployed. Global quantum ecosystem is now going through a rapid growth phase, which will likely be followed by a consolidation phase with mergers and acquisitions.

The economic and social significance of quantum technology is recognised and the greatest expectations for the quantum revolution are on quantum computing. The promise of solving some of the hardest computational problems known in a feasible time is getting closer as the hardware and software matures. Quantum computing is expected to have a similar kind of impact as AI on several societal and industrial fields.

Large-scale commercialization in the field is expected once quantum computers reach the first quantum advantage, i.e., they outperform in some way any classical computer in a computational problem of practical value.

VTT's report "Kvanttilaskennan kehittämisen tiekartta Suomessa" has analyzed some of the recent forecasts categorizing the market in three main segments: Quantum Computing Hardware, Quantum Computing services and Quantum Computing Applications. The minor segment includes quantum communication, sensing and instrumentation.

The report estimates that by 2030 the global Quantum computing hardware market is between 430 – 3200 M€.

The service and software market is estimated to grow bigger than the hardware market and by 2030 the market size is estimated to be between 1 100 – 26 000 M€.

The estimates of the benefits that the quantum computing applications generate are quite varying. As an example, BCG estimates the benefit to be between 5 000 – 10 000 M€ within the next 3-5 years and to be 450 – 850 billion € within the next 15 – 30 years.

Quantum computing

There is no consensus on the exhaustive set of problems that quantum computers will be able to tackle, but research is concentrated on the following types of computational problems[1]:

Simulation: Simulating processes that occur in nature and are difficult or impossible to characterize and understand with classical computers today. This has major potential in drug discovery, battery design and fluid dynamics, similar problems can also be found in finance in derivative and option pricing.

Optimization: Using quantum algorithms to identify the best solution among a set of feasible options. This could apply to route logistics, scheduling, and portfolio risk management.

Machine learning (ML): Identifying patterns in data to train ML algorithms. This could accelerate the development of artificial intelligence (for autonomous vehicles, for example) and the prevention of fraud and money-laundering.

Cryptography: Breaking traditional encryption and enabling stronger encryption standards. Quantum processors can also be used to create new encryption methods that require the availability of real hardware.

Growth enablers

It is essential to have direct experimentation with quantum devices to understand what they are capable of in practice; applications for established quantum capabilities may then be sought. In this arena it is important to facilitate the combination of the best of various quantum systems to build new devices, capabilities, and platforms based on multiple different physical realizations.

An essential asset is the Finnish Quantum-Computing Infrastructure (FiQCI) that has just recently been opened for academic use. The mission of FiQCI is to provide state-of-the-art quantum-computing services such as computing time and training to the Finnish RDI communities. This includes providing a hybrid high-performance-computing and quantum-computing (HPC+QC) platform for developing, testing, and exploiting quantum-accelerated computational workflows. Through FiQCI, Finnish researchers and developers have access to one of the most powerful hybrid HPC+nQC resources in the world, available for application layer quantum accelerated research and

[1] https://www.bcg.com/publications/2021/building-quantum-advantage

development. Thus, FiQCI and its further development is one of the key growth enablers in Finland.

In addition to FiQCI there is also a need for open-access quantum-hardware infrastructure to enable researchers and SMEs to work together to develop open-architecture-based critical components to the supply chain in Finland. Currently, OtaNano infrastructure is already providing millikelvin cryostat time including qubit measurement capabilities, but from the point of view of quantum firmware and operating-system development, OtaNano is lacking an actual QPU station with several qubits. Such extension to OtaNano infrastructure can work as a growth enabler not only to the quantum hardware and firmware companies, but also to the system integrators who may consequently have first-hand access to new improved components and firmware.

It is important to note that while useful quantum computers with very large number of qubits could still take up to the end of this decade to realize, the demand for some critical technologies like control hardware and cryo-electronics is clear and present where Finland's expertise could be harnessed immediately for commercial opportunities.

Another asset is the Micronova cleanroom facility in Espoo, Finland, operated jointly by VTT and Aalto University, enabling applied research and small-scale commercial manufacturing of quantum microsystems for the needs of quantum computing, communication and sensing. Micronova, part of the national Otanano research infrastructure, plays a significant role in quantum technology R&D in Finland. Efforts should be made to further commercialize and expand the potential of Micronova through international projects to fund development for more fabs in Finland.

The experimentation with the available QC's deepens the understanding in search of the NISQ-era (Noisy Intermediate-Scale Quantum) algorithms that could offer quantum advantage for meaningful problems. Typically, these exercises include a) identification of the key problems that need QC as a tool for solutions; b) characterizing problems and c) characterizing their quantum requirements d) the algorithm design and e) test runs.

Near-term quantum computers and quantum emulators are important to realize transformative approaches with advantages for working on problems that can be mapped to a quantum algorithm or to a quantum system for computation or simulation. Developing new quantum algorithms suited to NISQ devices, and formal methods of resource estimation for evaluating their potential for quantum advantage, could facilitate near-term progress in this frontier.

Collaboration and continued discussion across computing, mathematics, engineering, and other application domains will be needed to reveal what can—and cannot—be accomplished uniquely with quantum technologies, and to achieve this potential in actual devices.

Important research areas identified include development of open-architecture modular software designs, methods for mapping computational problems to the specific hardware configurations of early devices, and exploration of programming languages built upon hardware-informed semantic models. Major research opportunities include further development of system architectures and abstractions and community-acceptable metrics and standards (once technologies have reached the appropriate level of maturity) for use in system validation, verification, and performance benchmarking and to inform technology selection and system optimization for specific use cases.

Longer term, the use of abstractions to enhance productivity will be needed, once quantum resources are more plentiful. We must establish the sorts of modularity and layering commonly needed for scalable systems.

Joint efforts in developing common terminology and metrics will allow researchers in diverse groups to communicate more clearly and encourage better exchange of ideas and enable faster progress. Metrics also need to be further developed beyond the current T1, T2 and quantum volumes.

Estimating resources for quantum algorithms using realistic quantum computing architectures is an important near-term challenge. Here, the focus is on reducing the gate count and quantum circuit depth to avoid errors from qubit decoherence or slow drifts in the qubit control system. Different types of quantum hardware support different gate sets and connectivity, and native operations are often more flexible than fault-tolerant gate sets for certain algorithms. The optimisation of specific algorithms to specific hardware is an active research area.

To reach fault tolerance at large scales it is important to understand and experimentally realize quantum error correction, calling for improved gate, readout, and reset fidelities. Key requirements also include fast optimal characterisation and control for multi-qubit systems, including use of measurement, feedback, and novel encodings; development and exploration of novel universal computing paradigms in the fault-tolerant domain; new improved qubits; and use of current devices to expand the limits of qubit performance.

Quantum enabled data business

In modern data business the ecosystem actors encompass both the hardware and system software, providing the technological basis for connectivity (connect), computational capacity (compute) and the storage of data on servers (store). Trusted data spaces that enable secure domain-specific and cross-domain data interaction are indispensable for the implementation of tomorrow's data-driven, platform-based business models.

In many cases platform business models allow users (producers) to create value on the platform for other users (consumers) to consume. The actual use cases evolve or emerge through usage. At the technology layer, external developers extend platform functionality using APIs.

In traditional contexts such as data centers, hardware is a readily available, standardized commodity. The users of enterprise software and other similar types of software can freely choose which hardware (e. g. PCs and notebooks) they use and are thus able to avoid dependence on individual manufacturers.

The advent of the cloud has led to the development of network effects and economies of scale. The user companies are in many cases consumers of technical cloud services that are operated and provided as a service by specialist providers. The huge investments required due to the need for a global presence mean that there is a tendency for a handful of market-leading cloud infrastructure providers (hyperscalers) such as Microsoft, AWS and Google to form oligopolies and try to lock users into their platforms.

This makes it possible for the cloud companies to build huge global data spaces, which provide them with a global competitive advantage when it comes to innovative applications and in particular AI and machine learning.

The same kind of development, i.e., cloudification, may also happen to quantum computing except for offering both classical and quantum computing in combination. This opens new research topics like hybrid workflows, computing task partitioning and offloading and latency minimisation between classical and quantum resources.

Based on the cloudification scenario following ambition levels especially for the software companies can be seen:

1. Becoming the “quantum hyperscaler” rising to the level of the global tech giants disrupting the data business.

2. Becoming an indispensable partner to the emerging“quantum hyperscalers".

3. Bringing innovations to the market that prevent formation of "quantum hyperscaler" in the first place.

IPR and Quantum Software

In this rapid development phase of quantum technology, the lifetime of patents is relatively short, compared to the long timeframe required to commercialize quantum technology. Therefore, Intellectual Property should be handled in such a way that businesses can harness and commercialize it fast without hindrances. The licensing of the IP to companies or academic researchers who want to spin out should be handled effectively and with reasonable terms. IPR needs also to be valued neutrally. Many universities and RTO´s in Finland are already aligned with this development and have sufficient IPR processes in place.

The quantum computer as a product requires standardization and integration of all its building blocks. Open and standardized API interfaces between different hardware components would speed up the development cycles. BusinessQ ecosystem players could play a role in developing de facto or actual standards.

It would be beneficial to understand why full-stack quantum-computing companies have started to emerge. Is it simply the beginning of the mergers and acquisition phase of market development? Is it related to the need to co-design solutions? Is it related to the missing standardization landscape and if so is it an indication that such a standardization is premature or that there is precisely a massive opportunity for BQ members?

Quantum-computing algorithms are currently closely connected to the software and hardware that's used to implement them. Typically the theoretical work related to algorithms is implemented in software and, as much as possible, practically implemented on different noisy systems to assess algorithm performance and resource requirements. This indicates that arrangements enabling hardware and software to improve together should be encouraged in Finland.

Quantum-computing software development benefits from engagement with experts in areas such as simulation and machine learning. Collaboration of quantum and classical programmers should be encouraged also in industrial settings.

Quantum communication

Communications systems based on quantum components offer levels of security potentially beyond that which we can achieve now, which will allow us to transfer sensitive information with confidence. The fundamental laws of quantum physics guarantee unbreakable encryption provided. This has been an area where the Finnish community has been active for decades. This area is related to the telecom industry and New Space topics.

Quantum sensors

New sensor systems will give us the ability to detect and visualize movement, light, gas emission, electric fields, and even gravity, with unparalleled precision, which could impact on fields as diverse as medical imaging and oil exploration. Sensors are used in everyday technologies to detect motion, sound, and light. They range from the billions of low-cost motion sensors in mobile phones to high-end systems in healthcare and Earth observation. Quantum sensors offer a step change in performance: more sensitive, accurate and stable than current technology. Several Finnish companies are active in these fields.

International collaboration

The international collaboration happens in different levels and B2B collaborations are typically handled by individual companies. There is also a lot of potential offered by joint EU funded projects. Ecosystem-level collaboration is an important platform to enable such collaborations. However, it is important to track the effectiveness of these initiatives to ensure real progress.

Some key partners in the Finnish Quantum Ecosystem have signed Memorandum of Understanding between The National Quantum Office of Singapore. Similar type of arrangement has been signed with the State of Colorado and the Government of Finland. India and Finland will establish an Indo-Finnish Virtual Network Centre on Quantum Computing and it will attempt to stimulate innovative research and development projects to address needs of both nations.

The purpose of these arrangements is to accelerate the development of quantum technology hardware components, algorithms and applications, and collaborate in the areas of quantum-accelerated high-performance computing and both terrestrial and satellite quantum communications. The MoU will also pave the way for knowledge exchange on national strategic roadmaps for quantum technologies.

3. The Finnish Quantum industry and its needs

Majority of the Finnish quantum industry is related to hardware and component manufacturing, but the software companies start to emerge. The Finnish companies are well positioned in the international value chains and some of them have substantial growth potential.

SWOT analysis

S: Finland is exceptionally strong on the global scale in commercializing some key quantum-related technologies such as dilution refrigerators and quantum computers.

S: Finland has been able to create its strong position in a very cost effective way.

S: Finnish universities are agile and solution-oriented

S: Presence of a system integrator capable of bringing together and coordinating all the needed competences and components that will make up a commercially viable quantum computer

W: Lack of specifically trained talent and people in the IT sector, who understand what quantum computing could offer to them

W: Lack of funding for companies to build major proprietary infrastructure to serve the market and supply chain

W: Lack of open-access and open-architecture quantum-computer testbeds to develop critical components and low-level software for the quantum supply chain.

W: Lack of funding to integrate critical hardware and software components into existing quantum-computer products.

W: Lack of streamlined and uniform spinout processes in universities, especially including lack of successful third-party valuation of quantum IP.

O: Extend the existing infrastructure to test and develop quantum-computer components and software from any supplier, including quantum processors, control HW, control SW, and cryogenics.

O: Take seriously the training of the programmers in the existing companies for quantum.

O: Strong talent in RF electronics and low-temperature physics may be harnessed for building world-leading quantum control HW companies.

O: Develop testbed to verify, validate and benchmark claims by quantum organizations around the world.

T: Quantum HW or SW may mature more slowly than expected, or the problems where quantum provides benefit turn out to be limited.

T: Ramping up the software competence can be slow

T: Finland may not be able to develop its quantum software industry fast enough compared to other countries, and hence not to grasp as large fraction of it as it seems to grasp in the hardware markets

T: The exceptionally strong position of Finland in the quantum-technology industry may degrade if there is not enough governmental support to coherently foster the flagship companies and their supply chain.

What are the key business opportunities and business models?

- The greatest opportunities for Finland lie in fostering its quantum unicorns and soonicorns to grow their market share and build scaled-up production infrastructure.
- In the short to mid-term, there is also a great opportunity in building focused new startups that can provide advanced solutions to system integrators such as novel QPU design software, room-temperature control electronics, cryogenic electronics, automation and control software.
- There is a global need for an independent validation, verification and benchmarking provider.
- Technological superiority: the fastest developers will survive, the slow ones will face challenges.
- Consultation of where and how to apply quantum will be a big need.

List the critical infrastructures and testbeds. How to take advantage of the current ones? What is needed in the future?

- The local quantum computers of FiQCI and its readily available quantum-computing services and support are critical to boost the quantum ecosystem in Finland. Further development of the FiQCI infrastructure is a key success enabler of Finland.
- Foreign quantum computers available in the cloud and those to arise in the EU in the framework of EuroHPC provide an important complementary platform to that of FiQCI for companies developing algorithms.The cost, speed in iterative algorithms, and access to the latest HW can be bottlenecks.
- Quantum hardware is not in itself sufficient, we need interfaces (QPU clusters etc) that take in data, feed it into quantum hardware and finally return results to customers. Combination of quantum and HPC can be valuable both for iterative quantum algorithms and for testing and debugging quantum solutions in simulators. Here, the LUMI supercomputer infrastructure, the most powerful in Europe, is central. The role of artificial intelligence (AI) and machine learning (ML) for quantum technologies is expected to increase rapidly. Therefore, having a unified

infrastructure combining HPC, quantum computing, and AI is a key asset for further development of both hardware and software stacks.

- OtaNano is a great asset for research and development and for training talent. We need to further develop OtaNano by building open-access open-architecture quantum-computer testbeds which can expand the training opportunities of talent and enable development of key hardware and software components in startups.

List of critical competences. How to take advantage of the current ones? What is needed in the future?

- Finland is very competent in the global scale in commercial dilution refrigerators and quantum computers, which Finland should take advantage of in fostering export and technology sovereignty, attracting talent, and enabling startups to have their first customers.
- Finland has good-quality training in fields related to quantum technology and focused programs but the scale is too small to serve the growing quantum industry. For example, programmers need to be retrained for quantum software and algorithms, QPU design and quantum sensing requires proper knowhow of quantum physics, and cleanroom process engineers will be needed in the expanding industrial cleanrooms.
- The ability to integrate quantum hardware with classical software systems such as HPC will be essential. One should understand where quantum is useful, how to test, debug and maintain quantum software, and how to rely on the results.

How to ensure commercial applications of quantum tech, what kind of actions are needed?

- In general, we need to foster the Finnish ecosystem where companies collaborate with research organisations and each other.
- The dilemma is that current quantum computers are not useful for real-life problems but when they are then it may be too late to join the race. Thus Finland needs to support its emerging and growing quantum industry by governmental investments into infrastructure that enables technology development and provides revenue to the companies, to foster them to grow.
- Related to the above points, the following actions are needed:
    - Continuously deploy quantum computers in Finland to ensure that Finland has the latest hardware and knowhow.
    - To complement the local machines, provide access to international cloud quantum computers through a national hub to the academia

and the industry, not only to the largest players but also to smaller entities.

- Establish funding programs for algorithms and applications and for integrating critical hardware and software components into existing quantum-computer products
- Financially support and invest into young hardware and software companies
- Provide state aid for chip fabrication infrastructures for research, pilot-manufacturing, and manufacturing.
- Establish open testbed infrastructure for testing and experimentation of quantum hardware and low-level software.

What kind of engagement with quantum industry and application companies/public bodies is needed?

- Major ecosystem-building projects where all parties are properly funded so that the application industry can build its own quantum teams that can then efficiently work with those of the quantum industry.
- Follow-up development projects and experimentation with different use cases to get hands-on learnings.
- National quantum day where the Finnish quantum industry shows its greatest results to representatives of public bodies.

What kind of international cooperation is needed (opportunities/missing areas)?

- Support export of Finnish quantum technologies by organizing delegations and signing memoranda of understanding in the field
- Foster Finnish interests in standardization organizations so that the Finnish IP becomes parts of the standards bringing funds to Finland in terms of royalties. Finnish presence in these organizations is almost non-existent whereas some other countries have realized this opportunity.
- Push Finnish interests in export-control discussions such as those in Wassenaar, not to artificially restrict Finnish export.
- Support mobility such as internships and research visits
- Finland can become the global hub for:
    - Testbeds where companies and researchers from all over the world can come and try their ideas, both in terms of new hardware and software development.
    - Verification, validation and benchmarking services

- Quantum-chip foundry services

Based on the SWOT following ecosystem needs can be identified:

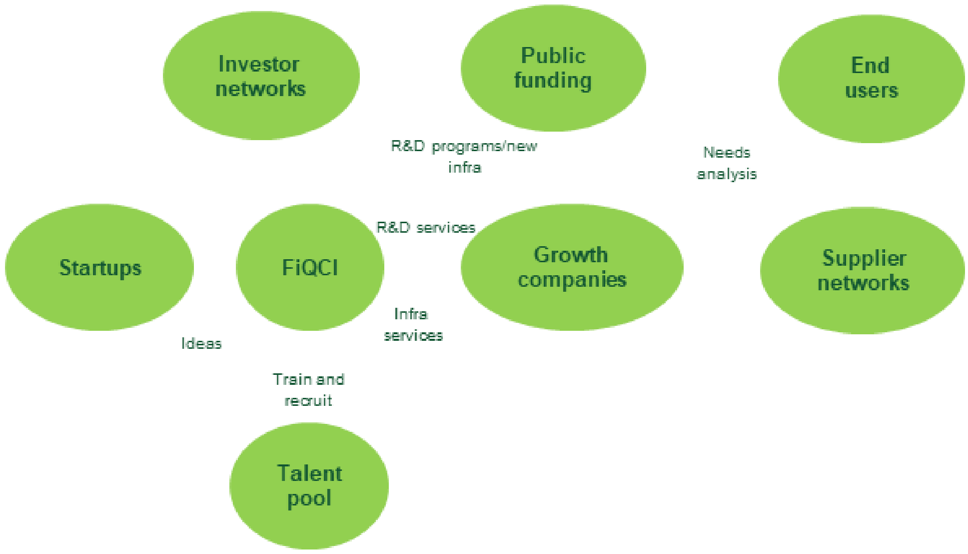
- Physical access to research and pilot-line quantum-chips fabrication facilities and commercial access to top-notch industrial quantum-chip manufacturing.
- Stimulate knowledge exchange, engagement and collaboration between businesses, research centres, and other organizations in clusters.
- Facilitate industry access to the excellent people, national facilities and diverse capabilities at the universities and RTOs
- Boost and harmonice the practices of knowledge and technology transfer from publicly funded organizations to innovative companies across Finland
- Extend OtaNano to host open-access open-architecture quantum-computer testbeds to drive innovation in areas such as low-level software, QPUs, room-temperature and cryogenic electronics and to train talent.
- Drive the development or demonstration of novel concepts, technologies or services
- Demonstrate the feasibility of new technologies or capabilities, or a new application of existing technology
- Validate technologies and services in a system context
- Support economic growth, helping high-potential businesses to progress new or novel ideas and secure follow-on-funding and investment.
- Ensure adequate funding and attention to emerging areas such as quantum software.
- Identify and explore the development of use cases for quantum computing
- Explore the development of early applications of quantum computing which are relevant to industry
- Analyze one or more use cases relevant to industry with the goal to understand hardware and software requirements and constraints necessary to reach a solution.
- Continuously deploy the latest local quantum computers to FiQCI
- Establish services to access to international quantum-computing systems
- Foster new startups such as by leveraging the strong talent in RF electronics and low-temperature physics, Finland could build world-leading quantum control HW companies.
- Develop services to verify, validate and benchmark claims by quantum organisations around the world.

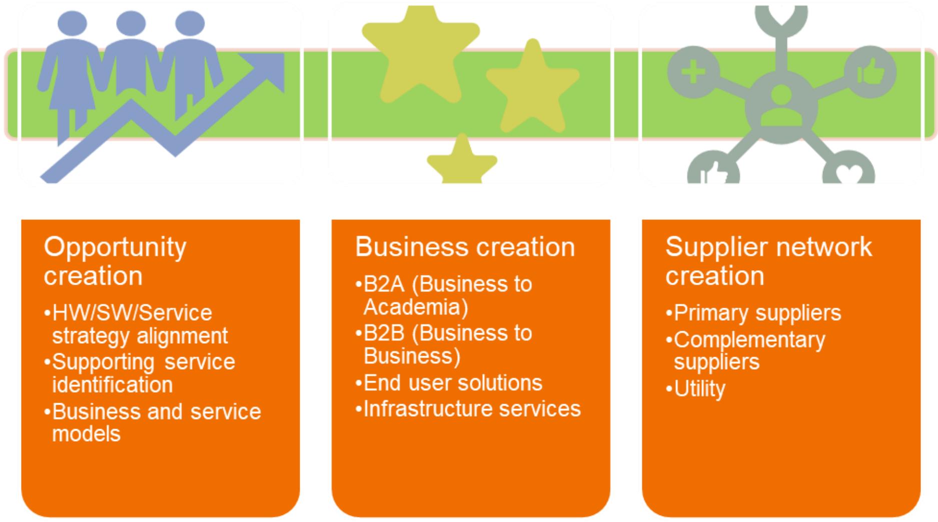
4. Business Roadmap

BusinessQ was founded in 2021 and currently it consists of 20+ members covering a wide spectrum of areas like hardware, software, consultancy and application testing. The BusinessQ ecosystem is still in its infancy and limited in size and composition; especially there is room for software and end user companies.

BusinessQ's main objective is to maximize the benefits of Quantum technologies for Finland and act as enabler for business growth. To implement this objective BQ needs operations and services that enable the QT businesses to work closely with Finnish innovation players and create new, quantum-enabled international business opportunities. In practice this could include joint projects, task forces and efforts in bringing people together, matchmaking, spreading the message of potential use cases, opportunities and successes.

Operation of BusinessQ has been initiated by VTT from within the InstituteQ structure. Now when the ecosystem is more mature and activities above are laid out in more detail, it would be an ideal time for BusinessQ to have a stronger operational structure. Ideally a business ecosystem is best led by an independent entity that is aligned with the needs of companies. It can be formed based on collective ownership of companies, research organizations and universities. That entity should then run the operation of BusinessQ and provide the ecosystem services to the community. The operation of such a structure will be funded by stakeholders and also public funding received from Business Finland for ecosystem creation/consolidation.





Picture 1 and 2. BusinessQ ecosystem players and BusinessQ main functions.

Major initiatives and themes

The BQ initiatives and major themes span the following four areas: a) ecosystem widening and networking, b) R&I capacity building and c) impact generation d) access to markets. Preliminary action plan in these four areas in short/mid/long term is presented in the following table:

	Short term (12 months)	**Mid term (12-24 months)**	**Long term (beyond 24 months)**
Ecosystem widening and networking	Create communication and dissemination plan Create networking plan Further develop time-boxed plans for quantum-computing infrastructure. Develop time-boxed plan for verification, validation and benchmarking lab	Define BQ services and value proposition Increase the number of members	Stimulate the software developers (working on kernel, algorithm, model or application level) and end user communities
R&I innovation capacity building	Initiate task forces Share best practices and create joint knowledge assets Organize quantum-computing challenges Deploy 20-qubit quantum computer to FiQCI for algorithm developers Initiate Finland's first open-access open-architecture quantum-computer testbed	Arrange greater access to QC resources through cloud service Build joint project portfolio Deploy 50-qubit quantum computer to FiQCI for algorithm developers Extend the open-access open-architecture quantum-computer testbed to tens of qubits for advanced QPU characterization and testing capabilities	Stimulate the interplay between algorithm design and QC hardware development Speed up development of HPC/QC integration Deploy quantum-supremacy and quantum-advantage computers to FiQCI for algorithm developers and applications Mature the open-access open-architecture quantum-computer testbed to cover typical maximum dye size of a multi-dye QPU

	Initial plans of a verification, validation and benchmarking lab Get access to global state-of-the-art quantum computers Plan and acquire funds for extending and establishing quantum-chip manufacturing facilities	Build-up of a verification, validation and benchmarking lab Initiate the building of R&D and industrial quantum-chip manufacturing facilities.	Verification, validation and benchmarking lab in full operation Quantum-chip manufacturing facilities in operation: R&D/pilot-line facility essentially doubling the current size and industrial pilot-line and production facility having fourfold the current size.
Impact generation	Create Helmi QC user group Identify new application areas for QC	Start PoCs	Build collections of use cases with reference implementations and data preparation
Access to markets	Joint exhibition attendance	Arrange conferences in Finland	Conduct market analysis Create business clubs

To create the wider effects, the end-user companies need to be engaged. This could be done by example joint projects and organizing quantum-computing challenges or specific end-user-groups dedicated to specific industrial problems. Projects are typically initiated in following steps:

Identify and define the applications which have potential for quantum-computational advantage and being relevant for the Finnish industry and society

- Create industrial task forces and select and refine 3-4 topics
- Formulate the most potential areas as follow up co-innovation projects

Collections of use cases with reference implementations and data preparation can be used to speed up the development.

Ecosystem services

Potential services that the ecosystem actors (e.q. RTOs, universities, consultants, funding organizations, and other companies) may provide to the new and emerging members are listed below. The content of the services needs to be defined. BusinessQ can act as an enabler and access point to these services.

Needs analysis and test before investing

- Quantum potential assessment
- Roadmapping with companies
- Co-creation workshops and hackathons
- Student thesis projects
- Fast prototyping
- Quantum accelerator services
- Testbeds and experiments

Skills and training

- Training events including theory and experiments
- HPC/QC computing environment training
- Short course

Support to find investments

- Advice to SMEs, business development
- Investor events and matchmaking with investors for SMEs
- Access to Finance -service

Support in commercialization

- Advice to SMEs, business development
- Sales and marketing, and market access support

Innovation ecosystem and networking

- Networking events
- Matchmaking support to find solutions and partners

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