Roadmap: Finnish Quantum Technologies by 2035

Co-created with quantum community

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Institute

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>> This roadmap is a call to action and collaboration >>

This document presents Finland's Quantum Technology Roadmap, extending the national focus beyond quantum computing to also encompass quantum communication and sensing. It captures the current state of collective discussion and remains shaped through continued workshops, debate and shared learning. Indeed, the roadmap is not a fixed implementation plan but a living framework that evolves through continuous community engagement. The value lies as much in the shared process as in the document itself, guiding future discussion, aligning next expectations and supporting informed choices as the field advances.

The enduring roadmap process is not about predicting specific breakthroughs but about creating the conditions for them to emerge. Today, the roadmap supports and invites the following actions:

For the Finnish quantum community

- Provide a shared view of development pathways across quantum computing, communication and sensing.
- Identify key technology needs and open research questions aligned with Finland's national strategy.
- Strengthen dialogue and collaboration in the existing ecosystems and clusters between research groups and companies by supporting joint projects, planning and target setting.

For the Finnish industry, funders and policymakers

- Offer a realistic yet ambitious picture of how quantum technologies may progress and where early value may emerge across value chain.
- Support decision-making by showing where investments, pilots and capability-building can have the greatest impact.
- Highlight practical entry points for adoption and opportunities to link existing strengths to quantum-ready applications.

For international partners

- Make Finland's focus areas and technological strengths visible to the global quantum community.
- Benchmark and enable identification of complementary expertise and opportunities for joint research and testbed collaboration.
- Position Finland as an open, reliable partner in developing interoperable and scalable quantum technologies.

Finland enters this roadmap process with strong momentum.

Decades of excellence in low-temperature physics, cryogenics, and microsystem engineering have evolved into a coherent quantum ecosystem spanning computing, communications and sensing.

Alongside Aalto University and VTT, quantum research and education are advanced across the University of Helsinki, Tampere University, the University of Eastern Finland, the University of Jyväskylä, the University of Oulu, the University of Turku, and CSC. Together, these institutions provide deep expertise in algorithms, devices, photonics, materials, and large-scale computing infrastructures, forming a broad and resilient scientific base.

Finland's industrial strengths further reinforce the foundation. IQM Quantum Computers has emerged as one of Europe's leading full-stack quantum-computer providers, delivering complete systems to research centres and supercomputing facilities. Bluefors is the global market leader in cryogenic systems, which are essential for operating most quantum processors. A growing group of high-potential companies, including SemiQon, Algorithmiq, Quanscient, Arctic Instruments, and QMill, accelerates progress in silicon quantum processors, quantum algorithms, multiphysics simulations, measurement electronics, and device characterisation.

In quantum sensing, Finland hosts a complete commercial value chain, from superconducting-sensor development at VTT to MEG systems deployed worldwide by Aivon and Megin.

Quantum communication research is advancing through national pilots and Finland's active role in EuroQCI, laying the groundwork for future quantum-secure networks aligned with European strategic goals.

Together, this distributed capability across industry, universities, and research institutes demonstrates both readiness and long-term commitment, providing a strong platform on which Finland's quantum roadmap and future ambitions can confidently build.

To achieve lasting impact, it is essential to prioritise and align national resources, skills, and initiatives along the most promising technology development pathways. This roadmap directly supports that goal by clarifying the direction, identifying gaps, and helping the ecosystem progress with a shared purpose.

Finland’s Quantum Technology Strategy 2025-2035

This roadmap builds on Finland’s Quantum Technology Strategy vision and focuses on operationalising the Strategy.

Ambitious goals

Finland’s Quantum Technology Strategy 2025-2035 sets an ambitious vision: to position the country as a globally competitive, highly capable and reliable actor in the quantum domain. By 2035, Finland aims to grow a multi-billion-euro quantum industry, create tens of thousands of jobs and ensure that quantum technologies are embedded in industry, public services and national security infrastructure.

Building strengths

A defining strength of Finland’s quantum strategy is its recognition of the broad technological scope of quantum innovation: It is not limited to computing alone but includes sensing, metrology, and communication. However, true value will emerge when these domains do not evolve in isolation, but reinforce one another through shared platforms, knowledge and objectives.

The strategy highlights Finland’s strong legacy in low-temperature physics, photonics, and superconducting technologies, as well as its leading capabilities in software and algorithm development. But it also warns of key vulnerabilities: talent scarcity, fragmented coordination and the risk of slow uptake by industrial end-users.

The strategy identifies the need for long-term investment in research, infrastructure, and talent for agile policy mechanisms that can keep pace with evolving global dynamics and for a quantum ecosystem that is not just scientifically excellent, but deeply connected, commercially agile, and internationally trusted. It acknowledges that much of the promise of quantum technologies will unfold over time, but that significant value can be realised even in the near term through hybrid and narrow-use-case solutions.

The pillars

The strategy establishes several strategic pillars that form the foundation for national advancement in quantum technologies. These pillars – spanning research excellence, infrastructure development, education, international collaboration, and economic growth – are not ends in themselves. Rather, they are enablers.

Summary of Finland’s quantum technology strategy.

> Finland’s Quantum Technology Strategy and this quantum technology roadmap form a dynamic toolkit together: One setting the high-level ambitions, the other charting the technology development paths and progress markers that will get us there. With the right coordination, commitment, and collaboration, Finland is well placed not just to participate in the quantum era but to shape it.

Technology foundation

What do we mean by quantum technologies?

Finland in the quantum race

The global race for leadership in quantum technologies is driven by the potential to reshape industries, defence and scientific discovery fundamentally. Nations recognise that securing an early advantage in these dual-use technologies is paramount for future economic competitiveness, national security and technological sovereignty. Quantum technologies are largely still emerging technologies; currently in a developmental phase that requires determined technological advancement. Quantum research and infrastructure are now strategic priorities worldwide.

Finland combines deep expertise in low-temperature physics, superconducting technologies, semiconductor technology, and photonics, along with the development of quantum materials, hardware, and algorithms. Ongoing efforts focus on advancing superconducting qubits and silicon- and photonics-based devices. National infrastructure, EU collaboration and active research teams across academia, applied institutes and industry form a robust innovation ecosystem.

Quantum computing for breakthrough science, business and efficiency

Quantum computing exploits the principles of superposition and entanglement to perform specific calculations more efficiently than classical computers. It has the potential to enable fundamental breakthroughs in materials, chemistry, and climate science, delivering transformative optimisation in energy networks, supply chains, and financial systems while also enhancing AI and machine learning applications. At the same time, quantum computing offers a potential pathway to reduce the growing energy demand of computation by enabling far more energy-efficient solutions for selected high-performance workloads. Finland has developed core capabilities in cryogenic control, qubit fabrication and quantum software, advancing superconducting, photonic and silicon modalities through close collaboration across universities, research centres and industry.

Quantum communication for secure data

Quantum communication utilises quantum states of light or matter to secure data transmission and distribute entanglement across distances. Tomorrow’s quantum networks has the potential to secure critical infrastructure, protect data end-to-end and form the backbone of a quantum internet. Finland participates in European pilot networks like EuroQCI, has developed modular photonic integration and low-loss connectors, and contributes to standardisation and cross-border testbeds.

Quantum sensing for next-level measurement in industry and science

Quantum sensors exploit extreme sensitivity to detect minute fields, forces and timing signals, with applications from brain imaging and geophysical surveying to industrial process control and environmental monitoring. Finland’s strong heritage in superconducting detectors and emerging photonic and spin-defect sensors underpins commercial devices and field-ready prototypes, poised to deliver next-generation precision and resilience.

Key questions for quantum technology development

There are many questions to resolve; this roadmap and its ongoing process aim to answer some while others have already proposed actions in the national quantum strategy.

- How can fundamental research, applied R&D and industrial innovation be aligned to pursue shared objectives?
- How can we involve scientific and industrial end-users early to co-identify and accelerate solutions to Finland-relevant problems?
- How can we leverage existing expertise and infrastructure to attract new talent and foster spin-ups, building a more impactful quantum ecosystem?
- How can we foster collaboration between defence stakeholders and quantum technology developers to co-create requirements and deploy secure communication and sensing solutions?
- What breakthroughs might emerge from cross-modal collaboration between various platforms?
- How do we integrate classical software talent in HPC, AI and DevOps into quantum toolchain and compiler development?
- Which standards and interfaces must be agreed upon now to ensure interoperability across hardware, control, software and applications?
- What end-to-end full-stack architectures from cryogenic control electronics through system software to user applications are needed to deliver usable and scalable quantum solutions?

> "Keeping up with development requires a national commitment and the ability to achieve 'more with less’.”
> Finland’s Quantum Technology Strategy 2025-2035

Technology foundation

Maturity and impact of quantum technologies

Quantum technologies encompass various hardware approaches, each at different stages of development and offering unique advantages. Quantum sensing leads the way, having already been commercially used in medical imaging, GPS and defence applications. Quantum communication is emerging through secure networks with quantum key distribution (QKD) enabling highly secure data transfer. Quantum computing is still in an exploratory phase as it works towards achieving fault-tolerant operation. However, it holds significant potential for profound transformation and large market opportunities, as its application areas are vast, and its impacts will grow substantially as the technology matures.

A broad range of potential application areas have been identified across the three quantum technology domains, all with significant societal and business relevance:

Quantum computing

Global systems, security and resilience
- Predict and prevent infrastructure failures (e.g., energy, telecommunications)
- Enhance crisis response through faster scenario modelling and more efficient resource allocation
- Optimise supply chains under uncertainty
- Detect and mitigate fraud and cyber threats

Scientific discovery
- Simulate new materials at an atomic scale (e.g., for batteries and clean energy technologies)
- Explore complex physical phenomena
- Solve currently intractable computational problems

Healthcare and wellbeing
- Accelerate drug discovery through molecular simulation
- Enable personalised medicine using genomic and clinical data
- Speed up vaccine and treatment development for pandemic response
- Model biological processes to gain a deeper understanding of diseases

Sustainability and climate
- Improve climate forecasting for better policy decision-making
- Design advanced clean technologies (e.g., solar panels, electric vehicle batteries)
- Optimise resource use in agriculture, energy systems and industry
- Increase computing energy efficiency

Quantum communication

Secure data transmission (QKD)
- Protect classified government and defence communications
- Secure financial transactions and data exchange between institutions
- Safeguard communications for energy, transport and healthcare
- Ensure enterprise data privacy and protection of intellectual property
- Enable global QKD via satellites for long-distance secure links

Quantum internet
- Enable distributed quantum computing across remote quantum processors
- Support secure cloud-based quantum computing services
- Facilitate fundamental tests of quantum mechanics over global distances

Advanced sensing and metrology networks
- Link quantum sensors securely across various locations
- Enhance measurement precision through networked quantum systems

Secure voting and identity verification
- Develop tamper-proof electronic voting systems
- Use quantum digital signatures to verify identity and secure transactions

Quantum sensing

Healthcare and wellbeing
- Utilise quantum-enhanced imaging
- Achieve early and precise disease detection with sensitive biosensors

Navigation and positioning (PNT)
- Enable precision navigation without GPS (e.g., underground, underwater, airborne)

Environmental monitoring
- Implement gravitational field sensing for geological surveys and resource exploration (e.g., oil, gas, minerals)
- Detect pollutants and monitor environmental changes

Security and defence
- Advanced surveillance and reconnaissance technologies (e.g., ghost imaging, quantum radar)
- Detect hidden objects or people
- Enhance object detection (e.g., submarines, mines) with quantum magnetometers
- Improve intrusion detection in sensitive areas

Industrial process control
- Monitoring temperature, pressure, flow and chemical compositions at an atomic level
- Provide accurate and comprehensive data for the development of fully autonomous industrial operations

Fundamental scientific research
- Utilise quantum metrology for fundamental physics (e.g., gravitational waves, atomic physics, cosmology)

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Roadmap for quantum computing technologies

This section outlines the technological development path for quantum computing in Finland towards 2035. Ultimately, the roadmap as a process is not about predicting specific breakthroughs but about creating the conditions for them to emerge. Its purpose is therefore to identify and guide how we achieve the ambitious goals set out in the national quantum strategy across three domains: hardware, software and applications.

Hardware
Development spans superconducting, silicon and photonic qubits from fabrication to cryogenic platforms. A critical priority is optical integration technology for both control and readout using hybrid superconducting–optoelectronic components to achieve the energy efficiency required for the million-qubit era. Efforts also advance energy-efficient superconducting classical electronics, on-chip thermal engineering with solid-state cooling, and the scaling of hardware beyond the C-band. Finland's unique strengths in wafer-scale device engineering further support progress towards manufacturable, large-scale quantum processors. Research also advances new materials and junction technologies to ensure long-term coherence and future scalability.

Software
Evolution from calibration routines and NISQ-era error management through to full-stack compilers, real-time error correction firmware and hybrid classical-quantum orchestration.

Applications and use
Progress from identifying high-value pilot problems and demonstrating utility on early devices to deploying end-to-end workflows and scalable services for business and research users.

The roadmap highlights the need for strong international collaboration and supply chain integration in all modalities. While Finland's strengths currently lie in superconducting technology, the roadmap brings together parallel development tracks in silicon and photonic qubits and acknowledges that success in all modalities will require global partnerships and integration into international value networks. In future, additional modalities such as trapped ion and neutral atom-based approaches may also be included as capabilities evolve.

This section includes the following contents for your perusal and actions:

- **Overview** summarises milestones and key development goals for hardware, software and applications in three timelines towards 2035 aligned with the national quantum strategy.
- Deep dives for hardware, software and applications roadmaps with **detailed development goals by 2027, 2030 and 2035.**
- **Summaries** for detailed roadmaps including **highlight examples** for each timeframe that are particularly critical for achieving the goals, **"What if"** considerations to activate alternative futures thinking and possible disruptions, and findings for Finland's **focus and strengths.**
- **Research questions** for selected technologies to pinpoint gaps and ensure solutions address real-world needs.

This section includes also **key terminology** to clarify the roadmap documentation.

Quantum computing technology roadmap

Overview by 2035

	Hardware	Software	Applications & use	Milestones and targets*
By 2027	Reliable, repeatable multi-qubit chip fabrication. Scalable cryogenic and readout control electronics for hundreds of qubits.	Fully automatic calibration and pulse tuning across growing qubit arrays. User-accessible error-mitigation primitives in the SDK.	Pilot projects with Finnish industry to validate real-world value. Shared "quantum-working" benchmarks.	> 300–400 qubit operational system (2-qubit operation errors less than 0.03%) > Quantum advantage in initial use cases via error mitigation > 15 end-user companies have invested in the research and deployment of quantum technology
By 2030	Beyond-1000-qubit quantum computer control electronics using hybrid optical-electronic interfaces for energy efficiency. Seamless integration of multiple qubit modules. Standardised interfaces so new modules plug in easily.	Sub-μs error-syndrome feedback. Runtime-driven dynamic ancilla allocation.	Validated heuristic algorithms on early logical-qubit runs. Co-developed industry pilots showing clear advantage.	> Tens of logical qubits operational using about 1,000+ physical qubits > Quantum advantage in various application areas through effective error correction and mitigation > 50 end-user companies have invested in the research and deployment of quantum technology
By 2035	High-volume reliable qubit manufacturing lines. Built-in real-time error-correction feedback. Integrated quantum-system-on-chip architectures leveraging optical multiplexing for massive scaling.	Turnkey software stack that hides low-level quantum complexity. Autonomous orchestration of continuous error-correction cycles.	Quantum tools embedded in everyday R&D workflows. Proven commercial impact in multiple industries.	> Finnish device and component manufacturers are global market leaders > World-leading Finnish quantum software sector powering enterprise solutions

*Based on Finland's Quantum Technology Strategy 2025-2035

Quantum computing technology roadmap

Hardware development in superconducting qubits by 2035

	Scaling & fabrication	Control electronics & infrastructure	Operating environment	Fidelity & coherence	Connectivity
By 2027	Scale qubit counts towards 400 while improving coherence and gate fidelity. Establish millikelvin-compatible packaging and module-assembly workflows. Advance pilot lines with flip-chip and on-chip thermal engineering. Demonstrate initial operation beyond C-band (4–8 GHz).	Control hundreds of qubits at millikelvin with co-designed cryo-ASICs and backends. Pilot low-power hybrid control and readout technologies (e.g. JoFET, optoelectronic, bolometric) for scalable computing.	Uniform, well-shielded cryogenic environments for repeatable quantum operation and rapid cycles. Integrate advanced on-chip thermal management, including solid-state cooling demonstrators. Stand-up test beds for quantum components/systems.	Refine conventional and novel materials (e.g. aluminium, silicides and Nb-trilayer junctions), layouts and control pulses to achieve coherence times >100 μs and two-qubit gate error rates <0.03% across qubit arrays..	Balance integration complexity and signal integrity for dense low-loss on-chip links. Begin piloting hybrid optical-microwave links for inter-module connectivity.
By 2030	Transition from single-chip prototypes to multi-module production of thousand-qubit assemblies on established pilot lines. Integrate electrical refrigeration as a complement to dilution cooling. Qualify new materials for large-scale fabrication.	Low-temperature controllers with real-time error read & correction under tight power budgets. Demonstrate beyond-1000-qubit control and readout electronics based on the superconducting transistor (JoFET). Deploy hybrid superconducting–optoelectronic components for optical driving and readout to enable massive multiplexing.	Qualified multi-module cryogenic platforms with integrated solid-state cooling and electrical refrigeration demonstrating fully autonomous feedback-driven self-calibration.	Demonstrate error-corrected cycles without performance degradation as device counts extend to thousands. Continuously improve materials and packaging for maximum coherence.	Link modules and qubits into error-corrected fabrics with reliable low-loss interconnects. Establish hybrid optical-microwave links as standard for inter-module and quantum network connectivity.
By 2035	Integrate 300 mm wafer processes and modular assembly lines to produce tens of thousands of physical qubits across multiple interconnected factories. Adopt advanced materials as standard in high-yield, large-scale fabrication.	Millikelvin cryo-ASICs integrated with hybrid superconducting–optoelectronic control enable full low-power control, readout and feedback at scale. Optical–microwave multiplexing and advanced on-chip interfaces extend operation beyond the C-band and support large, low-maintenance module fabrics.	Modular cryogenics with >99.9% uptime. Self-managing, load-balanced cryogenics with minimal interruption and shared standards.	Deliver very high coherence (≫ 100 μs) and gate fidelities (< 0.01%) across very large qubit fabrics to support error-corrected logical-qubit operation. Live calibration/feedback maintains performance as machines grow.	Cross-fabric logical routing for arbitrary logical-qubit interactions across a global QPU network. Enable hybrid quantum systems with seamless superconducting–spin–photonic connectivity.
Summary	Establish reliable, high-yield fabrication of scalable superconducting qubit modules using advanced materials and 300 mm pilot processes. Modular assembly workflows and thermal engineering enable future expansion to multi-thousand-qubit systems.	Develop ultra-low-power cryogenic control and readout electronics capable of real-time error correction across thousands of qubits. Hybrid approaches combining superconducting, optoelectronic and bolometric components to enable efficient scaling and energy savings.	Build resilient self-managing cryogenic environments with integrated solid-state and electrical cooling for minimal downtime and high reliability. Standardised modular cryogenics support automated testing, calibration and continuous operation.	Maintain and extend coherence and fidelity as systems scale leveraging continuous calibration, improved materials, and adaptive control to achieve near-error-free operation at large scale.	Create reliable low-loss interconnects that link qubits and modules into coherent networks. Hybrid optical–microwave and superconducting links provide seamless connectivity across chips and technologies.

Critical highlights

- Research and industry efforts converging on common technology goals
- Dual-track development advancing current superconducting architectures while investing in scalable next-generation qubit technologies
- Optical-microwave I/O and cryogenic photonics as emerging scaling paths
- Uniform high-quality qubits and robust fabrication workflows across wafers and modules

What if?

- A high-Tc superconductor breakthrough enables operation at 1–4 K, slashing cryo-cost and complexity
- Emergence of alternative qubit platforms with comparable logical densities sparks hybrid-modality architectures
- Geopolitical or supply-chain disruptions cut off critical junction/ASIC materials, forcing rapid adoption of new fabrication or control schemes

Focus & strengths

- Cryogenic infrastructure and integration excellence
- Low-power cryogenic control and feedback systems
- Advanced superconducting materials and fabrication
- Hybrid optical–microwave interfaces and cryogenic photonics

Hardware development in superconducting qubits by 2035: Research questions

	Scaling & fabrication	Control electronics & infrastructure	Operating environment	Fidelity & coherence	Connectivity
By 2027	- How can industrial fabrication workflows be adapted for large-scale superconducting qubit arrays with uniform coherence and fidelity? - Which scalable superconducting qubit designs and materials best support future million-qubit architectures while maintaining manufacturability? - How can on-chip thermal engineering and fabrication enable operation beyond the current microwave band and support integration with electrical refrigeration?	- What control-architecture models enable sub-microsecond command, readout and reset with minimal dissipation? - How can low-power hybrid control and readout technologies (e.g., JoFET, optoelectronic, bolometric) be co-developed for scalable feedback and sensing? - How can control-electronics operate efficiently with solid-state and electrical refrigeration avoiding thermal load at the millikelvin stage?	- How should cryostat and wiring layouts be configured to provide stable temperature magnetic shielding and vibration control across large modules? - How can solid-state and electrical refrigeration be integrated to build resilient low-maintenance cryogenic platforms? - Which monitoring and automation tools can detect and correct environmental disturbances in real time?	- How can fabrication and material processes be refined to deliver coherence times above 100 μs and two-qubit gate errors below 0.03% across large arrays? - How can adaptive calibration and real-time feedback maintain coherence as system size increases? - Which material or junction innovations could further suppress crosstalk and decoherence?	- What interposer and wiring technologies deliver the necessary connectivity density without compromising coherence? - How can hybrid optical–microwave interconnects ensure low-loss high-bandwidth communication between superconducting and other qubit modalities? - What early standards are needed for hybrid inter-module links?
By 2030	- How can pilot-line fabs be scaled for consistent, high-yield multi-module qubit assemblies? - Which materials and processes ensure reproducibility in large-scale superconducting integration? - How can electrical refrigeration be industrialised to complement dilution cooling?	- How can control architectures support low-latency error detection and correction across modules? - How can low-power multiplexed readout and hybrid optoelectronic components be standardised for energy-efficient operation? - How can hybrid control stacks combine cryo-ASICs and photonic interfaces for scalable integration?	- How can modular cryogenics achieve autonomous feedback-driven calibration? - What facility-scale automation and diagnostics will maintain environmental consistency during long-duration runs? - How can test-bed standardisation accelerate cross-site validation and developer access? - Which approaches enable cryogenic platforms to operate with minimal maintenance?	- Which material and junction innovations sustain coherence and fidelity as device counts reach thousands? - How can dynamic calibration and error-correction feedback preserve performance across large systems? - Which diagnostic methods allow continuous monitoring without disturbing quantum operation?	- How can interconnect standardisation enable seamless workload distribution across QPUs? - Which interface standards should be established to ensure reliable inter-module connectivity and scalable logical-qubit communication? - How can hybrid optical–microwave networking be demonstrated at system level?
By 2035	- What factory-scale manufacturing controls ensure uniform device quality across thousands of qubits and multiple sites? - How can distributed fabrication networks coordinate module interchangeability and rapid repair? - Which advanced packaging techniques enable seamless cross-factory module swaps?	- How can energy-efficient control stacks be standardised to maintain performance as qubit numbers reach tens of thousands? - How can hybrid optical–microwave I/O and cryogenic feedback electronics support next-generation quantum processors? - Which design frameworks ensure long-term upgradeability as new modalities emerge?	- How can modular cryogenics be automated for >99.9% uptime to sustain fault-tolerant operation and standardised across multi-site quantum data centres? - What new cooling paradigms further reduce energy consumption while maintaining stability?	- How can high-Tc superconductors and alternative materials enable simplified cooling without degrading coherence? - What predictive-maintenance and self-calibration strategies sustain fidelity in fault-tolerant systems? - Which measurement protocols verify long-term coherence across interconnected modules?	- How can cross-fabric logical routing enable hybrid quantum systems with seamless superconducting–spin–photonic connectivity while maintaining error-corrected operation? - What interoperability standards ensure mixed-technology quantum networks remain error-tolerant? - Which optical–electrical transduction technologies best support scalable quantum networking?

Quantum computing technology roadmap

Hardware development in silicon qubits by 2035

	Scaling & fabrication	Control electronics & infrastructure	Operating environment	Fidelity & coherence	Connectivity
By 2027	Develop process controls and device models to ensure uniform behaviour and scalable qubit/interconnect design.	Demonstrate hybrid cryo-CMOS / JoFET control and readout for scalable qubit architectures.	Validate combined cryo-CMOS and qubit thermal budgets in standard dilution refrigerators.	Improve material isotopic purity and charge-noise suppression to extend single-spin coherence. Enhance interface engineering and material uniformity to minimise charge noise and variability across wafers.	Demonstrate dense nearest-neighbour exchange coupling in 2×50 spin arrays.
By 2030	Adapt 300 mm semiconductor lines to host initial spin qubit architectures.	Scale cryo-ASIC/DAC channel counts to address 1 000+ spins with sub-microsecond latency. Scalable superconducting multiplexing based on JoFETs for control and readout modules.	Pilot multi-zone cryostats with independent temperature control for electronics and qubits. Investigate solid-state or electrical refrigeration for simplified cryostat operation.	Optimise gate electrode layouts and pulsing schemes for uniform two-spin gate fidelity across multi-hundred-spin chips.	Implement on-chip multiplexed routing for crossbar and grid layouts of ~1 000 spins.
By 2035	Establish pilot-line workflows enabling rapid turn-around from multi-wafer fabrication to system-level testing.	Integrate superconducting and CMOS-based control electronics on-chip for energy-efficient multiplexed operation.	Achieve modular, serviceable cryogenic platforms offering >99.9% uptime and rapid module exchange.	Sustain coherence and stability required for error-corrected logical operations across multi-wafer systems.	Establish error-corrected logical links between spin qubit wafers via hybrid interconnects.
Summary	Building from small test arrays to wafer-scale spin qubit integration with consistent device quality.	Co-designing cryo-compatible electronics that scale from hundreds to tens of thousands of spin channels.	Creating stable, serviceable cryogenic platforms and shared validation facilities.	Ensuring long spin lifetimes and uniform performance as systems scale.	Linking spins on-chip and across wafers to enable advanced interactions and error correction.

Critical highlights

- Ensure integration into global quantum value chains
- Advance hybrid cryo-CMOS / JoFET technologies for energy-efficient control and readout
- Promote cross-domain synergies (photonics, superconducting control, sensing)
- Explore cross-domain synergies (e.g., sensing, photonics, superconducting control stacks) where advantageous

What if?

- Increased public and private funding accelerates breakthroughs in materials, interconnects and cryo-electronics
- Delays in quantum interconnect development narrow the modular advantage of spin qubits and push timelines back
- Strong interoperability between spin platforms and another technology such as photonics sparks hybrid strategies that reshape development

Focus & strengths

- Cryo-CMOS electronics
- Hybrid silicon–superconducting control
- Modular multi-wafer fabrication
- Cryogenic test & validation infrastructure

2

Quantum computing technology roadmap

Hardware development in photonic qubits by 2035

Photonics-based quantum computing is advancing globally while Finland's strengths lie in research and component-level innovation. This roadmap outlines key development steps for photonic qubits, clarifying links to global value chains and promoting national coordination and international collaboration across computing, communication, and sensing domains.

	Scaling & fabrication	Control electronics & infrastructure	Operating environment	Fidelity & coherence	Connectivity
By 2027	Deploy new low-loss photonic material platforms enabling the integration of active PIC components (e.g., electro-optical modulators, frequency combs). Developing single-photon sources and detectors.	Deploy high-speed photonic switches and hybrid photonic–electronic control for low-latency operation. Standardised interfaces support hybrid modules.	Validate cryogenic-compatible packaging and establish dedicated photonic–quantum testbeds.	Minimise on-chip optical loss and demonstration of high-purity single-photon sources and detectors.	Demonstrate low-loss optical packaging and scalable parallel links for chip-to-chip integration.
By 2030	Establish fabrication lines specifically for active components based on new materials and single-photon detectors scaling beyond passive circuit manufacturing.	On-chip control circuits for over 10,000 channels, with modular architectures and real-time feedback.	Shared test labs with standardised protocols and robust field operation, including automated monitoring and diagnostics.	Generate 100-photon cluster states with >99% fidelity and standardised error correction protocols.	Scalable modular interconnects with <0.1 dB loss per link and cross-module routing for logical-qubit networks.
By 2035	Scale up pilot lines for full quantum photonic circuit fabrication embedding complex active components (electro-optic and acousto-optic modulators, frequency combs) at foundry level.	Specialised cryogenic control solutions enabling error-corrected photonic quantum systems with >99.9% uptime and maintainability in distributed environments.	Routine field operation of modular photonic modules with remote diagnostics and streamlined maintenance.	Logical photonic qubits with built-in error correction enabling scalable stable computation.	Cross-platform quantum networking via photonic interconnects, supporting interoperability with other qubit modalities and quantum communication systems.
Summary	Producing ever-denser arrays of integrated photonic components with high yield and uniformity.	Designing photonic control layers and driving electronics for low-latency high-density operation.	Establishing testbeds and infrastructure for reliable photonic-quantum operation.	Maintaining photon purity and minimising loss across complex optical circuits.	Linking photonic chips into larger fabrics with minimal insertion loss.

Critical highlights

- Strengthen national coordination and international collaboration
- Leverage synergies with quantum communication and sensing
- Establish shared test facilities and standardisation frameworks for photonic quantum validation

What if?

- A major global breakthrough in integrated photonics (e.g., room-temperature entangled photon sources) dramatically reduces loss and complexity
- A significant increase in national R&D funding for photonic quantum hardware expedites pilot-line capabilities and ecosystem growth

Focus & strengths

- Integrated photonic components and modules
- Advanced cryogenic packaging
- Scalable standardised manufacturing

Quantum computing technology roadmap

Software development by 2035

	Control firmware and software	Error management	System software and compilation	Hybrid classical-quantum integration
By 2027	Automated calibration, tuning and pulse control ensure stable qubit operation across expanding device arrays. Modular firmware–hardware interfaces enable upgrades and experimentation without full system revalidation.	Early integration of error mitigation and proof-of-concept QEC demonstrates measurable logical error suppression across small-scale devices.	Modular SDK and compiler backend for device-aware circuit mapping.	Standardised low-latency APIs enable efficient hand-off between HPC and small-scale QPUs.
By 2030	Scalable, (AI-assisted) control coordinates thousands of qubits across multiple modules with adaptive error diagnostics. Firmware co-designed with cryogenic electronics minimises latency and power overhead.	Demonstrate scalable quantum error correction routines achieving and sustaining logical break-even across extended operation.	AI-driven scheduling of error-corrected routines and workload partitioning.	Dynamic orchestration of distributed QEC workloads across heterogeneous quantum clusters enabling efficient resource sharing and synchronisation between QPUs.
By 2035	Fully autonomous self-correcting control firmware manages real-time calibration, decoding and error recovery across large-scale quantum systems. Standardised firmware architectures support interoperability between diverse quantum hardware platforms.	End-to-end fault-tolerant stacks integrate hardware-level decoders and adaptive multi-layer software protocols enabling sustained logical operation across large-scale quantum systems.	Unified abstraction layer auto-optimising logical workflows and third-party modules.	Fully automated hybrid workflows route tasks to optimal quantum or classical engines via global interconnections.
Summary	Control firmware evolves from automated stability tools into intelligent self-managing systems that coordinate and correct quantum hardware in real time ensuring scalable and resilient operation across diverse platforms.	Error management evolves into a unified hardware–software layer enabling sustained fault-tolerant quantum operation.	Software stacks evolve from device-aware compilers to unified AI-driven abstraction layers that auto-optimise logical workflows and integrate third-party modules seamlessly.	Hybrid integration advances from low-latency HPC–QPU interfaces to dynamic orchestration and, ultimately, fully automated workflows that allocate tasks seamlessly across quantum and classical computing nodes.

Critical highlights

- Mobilise software expertise to strengthen national quantum toolchains and control systems
- Advance error correction through open shared frameworks linking firmware, compilers and orchestration tools
- Build hybrid testbeds combining QPUs and HPC to benchmark scalable error-corrected workflows
- Foster co-design across hardware, firmware and software to speed up interoperability and commercial readiness

What if?

- Rapid progress in error correction shortens the path to fault-tolerant quantum computing
- Missing interface standards delay orchestration and integration across software stacks
- AI-based compiler and control tools evolve faster than expected, accelerating industrial uptake

Focus & strengths

- Error correction and fault-tolerance software stacks
- Cryogenic and control firmware co-design, AI-enhanced calibration and orchestration
- Hybrid HPC–QPU testbeds and open SDK frameworks

Software development by 2035: Research questions

	Control firmware and software	Error management	System software and compilation	Hybrid classical-quantum integration
By 2027	- How can firmware automate calibration and stability routines to sustain gate performance across a growing array of qubits? - What driver architectures will enable real-time multiplexed readout and pulse sequencing at scale? - Which monitoring tools can detect drift or fault conditions and trigger autonomous recalibration? - How can firmware scale its multiplexing and scheduling to thousands of qubits without ballooning overhead?	- Which mitigation primitives (e.g., zero-noise extrapolation or symmetry verification) offer the best trade-off bet ween overhead and error suppression? - Which hybrid mitigation-correction protocols give the best resource-efficiency trade-off at intermediate code distances?	- How can early SDKs and compilers abstract hardware differences while enabling reproducible benchmarking? - What validation methods ensure compiler outputs remain accurate as error mitigation and QEC are layered?	- What low-latency API and protocol standards best orchestrate hybrid routines between HPC clusters and quantum endpoints? - How can circuit knitting and workload partitioning be automated to distribute tasks optimally across classical and quantum resources?
By 2030	- How can firmware coordinate syndrome extraction, decoding and correction within qubit coherence times? - What architectures best support parallel execution of logical-qubit operations with adaptive feedback?	- What is the most practical route to scalable fault-tolerant logical qubits within existing hardware constraints? - How can error correction stacks be modularised to accelerate co-design across firmware, compiler and orchestration layers?	- How can compilers integrate QEC code generation to produce fully fault-tolerant gate sequences? - How can runtime systems dynamically allocate error-corrected workloads across heterogeneous devices?	- What scheduler designs allow seamless hand-off between classical preprocessing, quantum execution and classical post-processing? - How can ML-driven optimisation improve workload routing for error-corrected circuits without excessive complexity?
By 2035	- How can firmware ensure uninterrupted syndrome extraction and correction cycles in production environments? - What architectures support on-chip autonomy for local error management and seamless integration with higher-level schedulers?	- How can fault-tolerant architectures sustain logical operation across heterogeneous QPU clusters? - What benchmarks and open frameworks best validate full fault-tolerant performance?	- How can compilers automatically optimise fault-tolerant circuits for target application profiles and resource constraints? - What standardised abstraction layers enable plug-and-play use of third-party optimisation modules?	- What orchestration frameworks transparently distribute large-scale fault-tolerant workloads between quantum and classical environments? - How can monitoring and telemetry ensure reliable performance across interconnected hybrid clusters?

Quantum computing technology roadmap

Application and use of quantum computing by 2035

	Identification of use-cases	Demonstrating utility	Benchmarking and KPIs	Integration and adoption
By 2027	Co-develop and prioritise use cases with global frontrunners while identifying pilot opportunities aligned with Finland's industrial strengths. Identify small and medium-scale problems that can be addressed using early error-corrected devices.	Tailor and test algorithms on 400-qubit devices, showing modest but reproducible advantage in selected problem instances.	Develop baseline performance metrics and validation protocols for early quantum–classical comparisons focusing on transparency and reproducibility.	Connect early quantum devices with national HPC and cloud infrastructures through pilot interfaces enabling co-simulation, shared resource scheduling, and first user-driven experiments.
By 2030	Establish verified application workflows in selected focus areas demonstrating quantum-accelerated performance for well-defined tasks.	Integrate small-scale QEC routines into end-to-end stacks enabling execution of algorithms on tens of logical qubits and unlocking quantum advantage for use cases requiring deep circuits.	Establish shared benchmarking frameworks and reference workloads to assess algorithmic and hardware progress across platforms enabling credible cross-industry and academic comparison.	Deploy hybrid HPC–QC environments supporting automated orchestration, workload optimisation, and secure data channels paving the way for scalable pre-commercial quantum services..
By 2035	Finland recognised as a co-developer of quantum-enhanced solutions in global industrial and scientific domains.	Run full application benchmarks on 1 000 logical qubits demonstrating clear and repeatable performance gains over classical approaches.	Standardise comprehensive benchmarks and define key performance indicators (KPIs) for fault-tolerant systems ensuring consistent evaluation of performance, scalability, and resource efficiency across hardware platforms..	Quantum computing integrated as a standard layer in national and European digital infrastructures supporting continuous, fault-tolerant operation, and seamless interaction with classical HPC and AI ecosystems.
Summary	Identification of use cases evolves from early collaborative pilots to verified application workflows and, ultimately, established hybrid solutions delivering demonstrable quantum advantage across key sectors.	Algorithms are adapted and validated on early hardware gradually incorporating error correction and scaling towards full application benchmarks that confirm quantum benefit at scale.	Benchmarking progresses from basic validation metrics to shared frameworks culminating in standardised benchmarks and technical KPIs for fault-tolerant quantum systems.	Integration advances from pilot interfaces and hybrid orchestration to full embedding of quantum computing within secure interoperable European digital infrastructures.

Critical highlights

- Focus quantum applications on Finland's industrial strengths and global partnerships to accelerate adoption
- Integrate quantum, AI, and HPC ecosystems to enable scalable hybrid workflows
- Mobilise Finland's ICT talent to embed quantum systems into mainstream IT development
- Create transparent benchmarks and accessible tools to engage new user communities and guide investment

What if?

- Rapid adoption of open interoperable APIs accelerates industrial integration far beyond current projections
- Breakthroughs in error-correction heuristics enable new application domains years ahead of schedule
- Lack of credible fault-tolerant benchmarks undermines confidence in quantum performance and slows investment
- Early hype without validated pilots leads to disillusionment and delayed real-world adoption

Focus & strengths

- Integration excellence across quantum, HPC and cloud infrastructures
- Strong ecosystem linking hardware, software and industrial pilots
- Collaborative culture bridging research and industry for sustained adoption
- Expertise in hybrid modelling and simulation supporting scalable workflows

Application and use of quantum computing by 2035: Research questions

	Identification of use-cases	Demonstrating utility	Benchmarking and KPIs	Integration and adoption
By 2027	- How can mathematical quantum advantage identified in one problem class be transferred to multiple industrially relevant applications? - How can algorithms be designed to deliver practical value on early fault-tolerant devices? - How can algorithms be made robust to evolving hardware characteristics and error mitigation techniques?	- How can NISQ algorithms be tailored with error-mitigation to yield results beyond the best classical approaches? - Which hybrid workflows deliver the largest performance gains on target problems? - What pilot projects can demonstrate measurable utility in domains such as logistics optimisation or molecular simulation? - How can we prepare algorithms today to deliver practical value on early error-corrected devices once available?	- How can we establish standardised benchmark protocols and open data repositories to ensure reproducibility and ecosystem alignment? - What early benchmark suites best capture the performance of NISQ and early error-corrected devices across key algorithm classes (optimisation, chemistry, ML)? - How can benchmark data be transparently shared?	- Which APIs and platform features most effectively embed quantum routines into existing industrial workflows? - How can non-specialists be guided to invoke quantum services within familiar software tools? - What are the most effective models and mechanisms for accelerating and broadening the adoption of quantum computing?
By 2030	- How can problem formulations and quantum algorithms be tailored to the limited depth and connectivity of early fault-tolerant systems? - Which specific instances of optimisation, simulation or ML tasks map naturally to tens of logical qubits? - How can algorithms be developed and implemented to scale and deliver practical speed-up before full fault tolerance is achieved? - How can abstraction layers be created to hide quantum complexity from non-quantum developers?	- Can early FTQC devices enable empirically validated quantum heuristics that outperform classical methods on commercially relevant problems? - How does running hybrid FTQC routines compare to pure NISQ implementations in speed and accuracy? - Which deep-circuit use cases can reach logical execution on tens of logical qubits with small-scale QEC?	- Which KPIs most reliably quantify practical advantage achieved on early fault-tolerant systems across different domains? - How can benchmarking frameworks adapt to rapid advances in error correction and hardware–software co-design?	- How can schedulers and middleware orchestrate hybrid classical–quantum pipelines at scale? - How can Finland leverage its existing strengths to accelerate adoption and new business creation?
By 2035	- Which industrial challenges in drug discovery, materials design or complex optimisation will benefit from hundreds of logical qubits? - How can we model and demonstrate end-to-end quantum-classical workflows that tackle these problems at commercial scale? - What mechanisms ensure that proven quantum use-cases transition smoothly from pilot environments to standard R&D toolchains?	- What platform features and APIs will allow non-specialists to invoke quantum routines seamlessly within existing tools? - Which collaborative forums and consortia will drive multidisciplinary adoption and best-practice sharing? - How can verified quantum gains be sustained in continuous production use as hardware and software evolve?	- How can comprehensive benchmarks and KPIs for fault-tolerant systems be standardised to ensure comparability across platforms and algorithms? - What international frameworks ensure comparability of fault-tolerant performance metrics across hardware types and algorithmic domains?	- Which collaboration frameworks and consortium models sustain cross-sector innovation and best-practice sharing?

Key terminology

Logical qubit

A logical qubit is a stable unit of quantum information created by grouping multiple physical qubits to protect against errors. Physical qubits are prone to noise and mistakes making them unreliable on their own. Logical qubits can detect and fix these errors through quantum error correction enabling more reliable quantum computations. Logical qubits are not mathematically perfect, but they are significantly more stable than physical qubits and are essential for fault-tolerant quantum computing.

Fault-Tolerant Quantum Computing (FTQC)

FTQC describes quantum computers that have successfully implemented Quantum Error Correction (QEC) on a large scale. The goal of FTQC is to build quantum machines that can perform calculations with arbitrarily low error rates regardless of how long or complex the quantum algorithm is.

Noisy Intermediate-Scale Quantum (NISQ)

NISQ describes the current stage of quantum computing. In this phase, quantum computers are characterised by their susceptibility to errors and environmental interference, meaning their qubits are delicate and easily lose their quantum properties through a process called decoherence. These machines typically possess a modest number of qubits ranging from tens to a few hundred.

Key strategies for error management

Quantum computers are prone to errors because of the fragile nature of quantum information and hardware imperfections. Ensuring reliable computations is important for practical applications. There are three strategies to address these challenges:

Quantum Error Correction (QEC)

QEC aims to find and fix errors during quantum computations. It encodes logical qubits using multiple physical qubits for redundancy and employs auxiliary "ancilla qubits" to detect error types without disturbing data. Classical computers then process these error signals to apply necessary corrections enabling FTQC.

Quantum Error Suppression (QES)

QES encompasses methods designed to prevent errors from occurring or to minimise their immediate impact. This strategy focuses on enhancing the inherent quality and stability of quantum hardware and operations through techniques like robust qubit design, precise control pulses, and advanced environmental shielding. QES reduces the initial error rate making subsequent error correction less resource-intensive.

Quantum Error Mitigation (QEM)

QEM is a set of techniques used to reduce the effective error rate of quantum computations especially crucial for current NISQ computers where full fault-tolerant QEC is not yet practical. Unlike QEC's real-time correction QEM typically operates by classically post-processing results from multiple quantum circuit runs to extrapolate a more accurate output providing a path to useful information without massive hardware overhead.

3

Roadmap for quantum communication technologies

This section outlines the technological development path for quantum communication in Finland towards 2035. Ultimately, the roadmap as a process is not about predicting specific breakthroughs but about creating the conditions for them to emerge. While the national quantum strategy emphasises the importance of international collaborations, test networks, and the necessity for a national initiative, it does not define specific intermediate milestones for advancing quantum communication.

Quantum communication is progressing from research to deployment with pilot networks and early solutions already in place. The roadmap addresses three key questions: which components should be developed locally, which should be co-developed with international partners, and which ready-made solutions should be adopted. Hardware development is currently a major research focus with the TELQuant project providing a critical opportunity to demonstrate capability. Finland's leadership of the EU's QUEST project underlines strategic capabilities in defence-related quantum technologies.

To achieve technological progress and market leadership in this field, broad participation from research groups, companies, and public sector organisations is essential. For instance, in 2025 CSC and Nokia demonstrated a 1.2 Tb/s quantum-safe link between Kajaani and Amsterdam.

This roadmap assumes an increase in the number of research groups and envisions that stakeholders in Finnish classical data networks will expand their activities into quantum communication networks by leveraging their existing expertise and resources. Additionally, public sector entities play a vital role in establishing secure network solutions and serve as key users of these new capabilities. We also need agile start-ups that can establish themselves in the expanding global market by developing test networks. Equally important is strengthening research in software and applications, alongside active engagement with user industries to ensure solutions meet real-world needs.

This section on quantum communication is presented at a more general level compared to the computing section and it focuses on four domains: hardware components, system integration, software and applications. The identification of bottlenecks and preliminary research questions will nevertheless facilitate needed discussion on goals and means clarifying what is beneficial for Finland.

This section includes the following contents for your perusal and actions:

- Deep dives for hardware, system integration, software, and applications roadmaps with **detailed development goals by 2027, 2030 and 2035.**
- **Summaries** for detailed roadmaps including **highlight examples** for each timeframe that are particularly critical for achieving the goals, **"What if"** considerations to activate alternative futures thinking and possible disruptions, and findings for Finland's **focus and strengths.**
- **Research questions** for selected technologies to pinpoint gaps and ensure solutions address real-world needs.

Quantum communication technology roadmap

Quantum communication development by 2035

	Hardware components	System integration	Software & protocols	Applications & use
By 2027	Develop modular, high-performance quantum communication components for rapid testing, including fast single-photon sources and high-fidelity detectors at telecom wavelengths. Integrate photon-number and energy-resolving detectors into testbeds to advance quantum-light generation and detection. Prototype practical quantum-memory units and single-chip integrated photonics for CW-QKD emphasising efficiency, scalability, and standardised qualification.	Conduct field trials of small-scale quantum networks over fibre and free-space links. Develop management interfaces and optical packaging with 3D integration for connecting sources, detectors and memories. Validate trusted-node architectures for secure key distribution across pilot networks.	Establish national know-how for quantum internet software and protocol development building capability to integrate emerging hardware components into system frameworks. Define functional and performance requirements guiding component and interface design. Engage with international standardisation efforts to align early protocol specifications..	Small-scale pilot deployments validate end-to-end QKD performance (key-rate, QBER) in real-world settings, including both access and backbone scenarios. National accreditation framework for quantum key issuance established. Build user competence and cross-sector collaboration to identify high-value applications for early quantum network services.
By 2030	Scale industrial fabrication of standardised components including deterministic entangled-photon sources, miniaturised quantum memories, and single-chip CW-QKD photonics. Demonstrate integrated photon-pair and memory systems in multi-node testbeds linking terrestrial and satellite segments. Adopt efficient packaging and 3D integration for scalable pilot and metro-network deployment.	Demonstrate multi-node and repeater-based architectures with reliable operation across network layers. Integrate high-speed QKD electronics and low-loss optical platforms to enhance performance and scalability. Achieve seamless terrestrial–satellite connectivity through memory-enabled nodes and standardised system interfaces.	Deploy advanced QKD and entanglement-based communication protocols in pilot and metro-scale networks. Develop adaptive control and synchronisation layers enabling dynamic routing, network diagnostics and hybrid classical–quantum coordination. Contribute to international standardisation of interoperability and security protocols for multi-node quantum networks.	Operational quantum-secure services adopted in critical sectors providing trusted connectivity from user devices through enterprise networks to cloud and data centre environments. Hybrid quantum-classical security solutions standardised enabling seamless integration into existing digital infrastructure. Certified quantum communication services available for national and cross-border networks supporting both access and backbone requirements.
By 2035	Commercial quantum networks widely deploy modular high-performance components for light generation, encoding and detection. Advanced state encoding, modulation and detection schemes boost data capacity. Low-loss component platforms seamlessly integrate terrestrial, satellite and memory-equipped nodes for continuous quantum-state transfer.	Deploy large-scale hybrid quantum networks combining terrestrial, satellite and memory-equipped nodes. Implement autonomous network-control and monitoring systems ensuring fault-tolerant low-loss operation. Enable continuous quantum-state distribution across domains with certified global interoperability.	Implement autonomous, fault-tolerant protocol stacks enabling the transition to global quantum internet operations. Enable intelligent resource allocation, quantum error correction at network level, and cross-domain orchestration of quantum and classical services. Achieve certified international interoperability across terrestrial and satellite infrastructures.	Quantum services embedded into everyday workflows banking, sensing and secure cloud access at a global scale. Entanglement-based and quantum internet services provide secure connectivity for advanced computing, sensing and cloud applications underpinning future digital ecosystems. Governance, regulation and standardisation frameworks guarantee interoperability and trust in quantum-secure global data exchange.
Summary	Quantum communication hardware evolves from modular prototypes and quantum-memory demonstrations to industrial-scale standardised components that enable seamless high-capacity hybrid networks across terrestrial and satellite domains.	Quantum network integration advances from pilot-scale field trials to autonomous fault-tolerant hybrid infrastructures that seamlessly connect terrestrial, satellite, and memory-enabled nodes with certified global interoperability.	Software layers advance from basic QKD protocols to adaptive autonomous orchestration with built-in trust, compliance, and resilience for quantum internet services.	Quantum-secure communication expands from pilots in key sectors to certified cross-domain services embedded in critical infrastructures and digital ecosystems.

Critical highlights

- Speed up integration by establishing modular national testbeds for photon sources, modulators and detectors to accelerate co-development of hardware and protocols
- Mobilise network and telecom companies to co-develop, validate and deploy quantum-network solutions in collaboration with research and government actors
- Achieve integration of quantum-secured and entanglement-enabled services into mainstream cloud, finance and sensing platforms as part of future digital infrastructure

What if?

- Solutions prototyped in Finland become standard in EuroQCI trials and beyond giving Finnish industry a head-start when networks scale commercially
- New on-chip photon sources and detectors reduce optical losses by half accelerating progress towards long-distance entanglement distribution
- Universal open quantum-classical APIs drive mass uptake across finance, cloud and critical infrastructure
- Development of DV quantum repeaters stalls while CV repeaters and optical–microwave CV transducers advance rapidly shifting the technological path towards continuous-variable quantum internet architectures

Focus & strengths

- Telecom-wavelength photonics and single-photon source development
- Cryogenic integration and low-loss optical component expertise
- Trusted-node and satellite-assisted quantum communication pilots

Quantum communication development by 2035: Research questions

	Hardware components	System integration	Software & protocols	Applications & use
By 2027	- How can modular high-performance quantum communication components be designed for rapid experimentation and early standardised qualification ensuring interoperability between platforms? - What material and interface innovations enable low-loss, thermally stable and energy-efficient single-photon sources and detectors at telecom wavelengths? - How can photon-number and energy-resolving detectors with low dark counts be integrated into testbeds supporting advanced quantum light generation and detection? - What architectures best support the first practical quantum memory prototypes and single-chip integrated photonics for CW-QKD balancing efficiency, scalability and manufacturability?	- How can modular architectures and network management interfaces support the integration of terrestrial, satellite and trusted-node QKD systems? - What are the main system-level bottlenecks (losses, synchronisation, noise sources) limiting scalability and performance, and how can they be measured consistently? - How can scalable test systems validate component interoperability and environmental robustness?	- How can foundational quantum communication protocols be standardised and integrated into early network pilots? - What software frameworks support efficient key management, monitoring and orchestration for small-scale testbeds? - How can secure cross-domain orchestration bridge quantum and classical network layers, while maintaining data integrity?	- How can quantum-secure communication be integrated with existing digital infrastructure in finance, government and energy sectors? - What are the most effective hybrid-security approaches combining classical and quantum encryption methods? - How can user awareness, trust and competence be strengthened among early adopters and public-sector partners?
By 2030	- How can industrial-scale fabrication of reproducible photon sources, detectors and quantum memories be achieved with consistent quality and yield? - How can next-generation entangled photon-pair sources and quantum memories be co-designed and integrated in multi-node testbeds connecting terrestrial and satellite segments? - What packaging, 3D integration and cryogenic control techniques enable robust, field-deployable and energy-efficient components?	- How can hybrid repeater architectures and multi-node/metro-scale networks be validated through field trials with industrial users in critical sectors? - What methods ensure interoperability between heterogeneous network segments: terrestrial, satellite and quantum-memory-equipped nodes? - How can data- and control-plane functions be harmonised for reliable, low-latency and secure operation across domains?	- How can entanglement distribution, routing and error-recovery protocols be automated across multi-hop and multi-domain networks? - What control-plane architectures enable adaptive and policy-driven orchestration across heterogeneous infrastructures? - How can performance metrics and trust models be developed and standardised for benchmarking quantum network services?	- How can cross-sector pilots validate performance, interoperability and trust frameworks for large-scale QKD and entanglement-based networking? - What governance and business models best promote cooperation between industry, academia and government for a quantum-secure ecosystem? - How can networks support secure data exchange and identity management across critical infrastructures and cloud environments?
By 2035	- How can hardware reliability, lifetime and field serviceability be ensured across hybrid terrestrial–satellite infrastructures? - What global standards and certification frameworks are needed to guarantee interoperability and compliance of quantum communication hardware? - How can hardware architectures maintain long-term stability and energy efficiency while reducing cost and environmental footprint?	- How can standardised orchestration and interoperability frameworks coordinate key and entanglement management across global quantum networks? - Which system architectures deliver fault tolerance, resilience and energy efficiency at global scale? - How can space–ground integration be optimised to enable seamless scalable coverage and autonomous operation?	- How can adaptive orchestration software dynamically manage key distribution, entanglement routing and error correction across global hybrid networks? - What compliance and trust frameworks ensure lawful, auditable and interoperable quantum internet services across jurisdictions? - How can control and management layers enable resilient, autonomous and transparent operation with end-to-end observability?	- How can quantum-secure communication be seamlessly embedded into global critical infrastructure networks ensuring lawful, trusted and resilient operation? - What global standards and certification processes guarantee interoperability and compliance across sectors and borders? - How can quantum internet services enable secure integration of computing, sensing and communication, and what are their societal and ethical implications?

4

Roadmap for quantum sensing technologies

This section outlines the technological development path for quantum sensing in Finland towards 2035. Ultimately, the roadmap as a process is not about predicting specific breakthroughs but about creating the conditions for them to emerge. While the national quantum strategy highlighted key application areas for quantum sensing, it did not set specific intermediate milestones for this domain.

This section on quantum sensing is presented at a more general level compared to the computing section and it focuses on three domains: hardware, software and applications. The identification of bottlenecks and preliminary research questions will nevertheless facilitate needed discussion on goals and means clarifying what is beneficial for Finland.

Quantum sensing leverages Finland's strong foundation in sensor technologies. A notable example is the development of graphene-based microwave bolometers, which exhibit exceptional sensitivity and open new opportunities for scientific and industrial applications.

The immediate priority is to understand the requirements of different application domains and markets to guide research and development. This roadmap emphasises translating these needs into practical solutions through close collaboration with end-users and industry partners. A crucial first step is convening stakeholders to jointly identify the most promising application areas where Finnish expertise and market understanding align. These strategic choices must also consider defence, critical infrastructure, sustainability, and manufacturing needs while recognising the essential role of research applications.

This section includes the following contents for your perusal and actions:

- Deep dives for hardware, software, and applications roadmaps with **detailed development goals by 2027, 2030 and 2035** specifically targeting:
  - PNT & Navigation
  - Environmental monitoring
  - Industrial process control
  - Biomedicine
  - Defence
- **Summaries** for detailed roadmaps including **highlight examples** for each timeframe that are particularly critical for achieving the goals, **"What if"** considerations to activate alternative futures thinking and possible disruptions, and findings for Finland's **focus and strengths.**
- **Research questions** for selected technologies to pinpoint gaps and ensure solutions address real-world needs.

Quantum sensing technology roadmap

Quantum sensing development by 2035

	Hardware	Software	Applications
By 2027	Field-ready prototypes of quantum sensors (e.g., bolometers, magnetometers) are demonstrated. Scalable processes are established via 200 mm pilot fabrication runs for superconducting nanowire single-photon detectors (SNSPDs).	Basic firmware and calibration routines are embedded in prototype quantum sensors enabling automated noise suppression and device stability. Early software supports data acquisition and remote monitoring for pilot deployments.	Co-developed field demonstrations solving concrete industry and research problems with simple transparent benchmarks. - PNT & Navigation: Rugged atomic-clock and inertial demos in GPS-denied zones - Environmental: Water- and air-quality sensor trials in lakes and urban areas - Process control: Inline non-destructive testing pilots on factory lines - Biomedicine: Wearable OPM-MEG prototypes in hospital studies - Defence & signal intelligence: Quantum-enhanced signal detection pilots
By 2030	Scale up fabrication for arrays of SNSPD detectors and develop monolithic integration on photonic chips. Automated calibration and AI-driven optimisation become standard features.	Software platforms evolve to provide modular integration, automated calibration and AI-driven optimisation across sensor networks. Standardised interfaces and diagnostic tools enable scalable deployment and real-time performance monitoring.	Scaled pilot networks delivering actionable insights to end users. - PNT & Navigation: Integrated clock/gyro nodes in smart-grid and 6G timing trials - Environmental: Distributed quantum spectrometer network for watershed monitoring - Process control: Live inline spectroscopy for chemical and energy-grid optimisation - Biomedicine: Hybrid OPM-SQUID arrays for functional brain imaging studies - Defence & signal intelligence: Quantum sensor arrays for sensitive signal intelligence and operational surveillance
By 2035	Quantum-system-on-a-chip architectures integrate dense SNSPD arrays on photonic chips with auxiliary electronics for sensing and computing applications. Industrial-scale manufacturing supports robust packaging.	Fully autonomous software stacks orchestrate large-scale quantum sensor networks delivering real-time data fusion, predictive diagnostics and error correction.	"Quantum sensing as a service" embedded into critical national infrastructure and commercial workflows driving measurable sustainability and productivity gains. - PNT & Navigation: Commercial GPS-alternative services for drones, mining and maritime - Environmental: Pan-regional climate-monitoring meshes feeding policy and early warning - Process control: Self-optimising smart factories with closed-loop quantum sensors - Biomedicine: Continuous, non-invasive patient monitoring and brain–computer interface platforms
Summary	Quantum sensing hardware advances from robust prototypes and scalable pilot production, through modular integration and automation, to chip-level architectures and autonomous networks establishing a foundation for next-generation sensor technology.	Quantum sensing software advances from embedded calibration and remote monitoring, through modular integration and automation, to autonomous orchestration and seamless digital integration underpinning the reliable operation of next-generation sensor networks.	Scaling from co-developed pilots with industry, research and public-sector partners to "quantum sensing as a service" driving societal resilience, sustainability, productivity and national security. In addition, combining advanced sensor technologies with applied fundamental metrology expertise enables Applied fundamental metrology.

Critical highlights

- Joint validation platforms connect research and industry to test quantum sensors in real operating environments
- Cross-sector collaboration targets use cases where quantum sensors clearly outperform existing solutions
- Common calibration and data standards speed up interoperability and certification
- Active engagement of end-users and system integrators drives market adoption and scalable deployment

What if?

- Neutral-atom sensors outperform solid-state devices redirecting research and investment priorities
- Standardisation and certification progress faster than expected accelerating commercial use
- Strong market pull from energy, defence and healthcare speeds up large-scale deployment
- Material and fabrication limits slow scaling from lab prototypes to industrial production

Focus & strengths

- Advanced sensor modalities: high-resolution calorimeters, low-noise bolometers, qubit arrays for magnetic sensing, structured light sensors (polarisation, angular momentum), ultrasensitive gravitometers
- Scalable manufacturing: graphene-based bolometers, photonic and plasmonic detectors, atomic clocks
- Integration expertise: 3D packaging, modular arrays, quantum-system-on-a-chip architectures

Quantum sensing development by 2035: Research questions

	Hardware	Software	Applications
By 2027	- What process innovations are required to establish high-yield 200 mm pilot lines for superconducting nanowire single-photon detectors (SNSPDs)? - How can detector performance be optimised toward physical sensitivity limits while maintaining stability and scalability? - What performance thresholds define meaningful quantum advantage for different sensing applications? - How can integrated optical architectures harness structured light (polarisation, angular momentum) for enhanced measurement precision?	- How can unified software stacks be developed for data acquisition, control and calibration across different quantum sensor platforms? - What data formats and protocols ensure traceability and interoperability between experimental setups? - How can AI-assisted algorithms improve noise reduction and signal interpretation in low-photon or low-temperature sensing? - What secure data-handling methods are needed to protect sensitive quantum sensor information in critical infrastructures?	- Which applications beyond healthcare (brain-imaging) offer the clearest early benefit from quantum-level sensing? - How can laboratory demonstrations be translated into reliable field trials under real operating conditions? - What accuracy, stability and cost thresholds define when quantum sensors outperform classical alternatives? - How can early adopters and end-users be engaged to co-design test environments and validate performance?
By 2030	- How can modular sensor platforms integrate calorimetric, photonic and spin-based sensors into unified measurement systems? - How can fabrication workflows be adapted for the monolithic integration of SNSPD arrays on photonic chips while maintaining high yield? - How can scalable pilot-line processes deliver reproducible performance and calibration across diverse sensor modalities? - What design and validation approaches enable early deployment of ultrasensitive gravimeters in applied geophysics and Earth observation?	- How can modular software frameworks integrate multi-sensor networks and hybrid measurement systems in real time? - What open-source standards enable cross-platform compatibility between quantum and classical sensing interfaces? - How can edge computing and AI pipelines optimise calibration, error correction and data fusion close to the measurement site? - What protocols support secure and authenticated sensor data exchange across distributed infrastructures (e.g., telecom, defence, energy)?	- How can large-scale pilot programmes demonstrate cross-sector value: from resource exploration to secure navigation and communication? - What interoperability and data-fusion standards are needed to combine quantum-sensor outputs with classical sensing networks? - How can AI-assisted analytics extract actionable insights from distributed quantum-sensing data in real time? - What frameworks ensure trusted deployment of quantum sensors in critical infrastructures such as defence, telecom and energy?
By 2035	- What architectures enable the integration of dense SNSPD arrays into quantum-system-on-chip platforms for dual-use applications in sensing and computing? - Which materials and cooling architectures support maintenance-free operation for calorimeters and bolometers in extreme environments? - How can large-scale sensor networks contribute to applied fundamental metrology and gravitational mapping? - What architectures enable autonomous self-correcting operation in heterogeneous quantum-sensing systems?	- How can autonomous software agents manage large-scale quantum sensor networks with minimal human intervention? - What AI-driven metrology frameworks enable continuous self-calibration and drift correction across sensor fleets? - How can digital twins and quantum-enhanced simulations model entire measurement systems in real time? - What global standards and certification frameworks ensure trusted operation of networked quantum sensors in safety-critical applications?	- How can quantum-sensing infrastructures become part of global monitoring and metrology systems for climate, space and navigation? - What business and governance models enable continuous, autonomous quantum-sensing services at planetary scale? - How can certified quantum-sensor data support regulatory and security frameworks in sectors such as healthcare, defence and environment? - What socio-economic and ethical frameworks are needed to ensure equitable access and responsible use of quantum-sensing technologies?

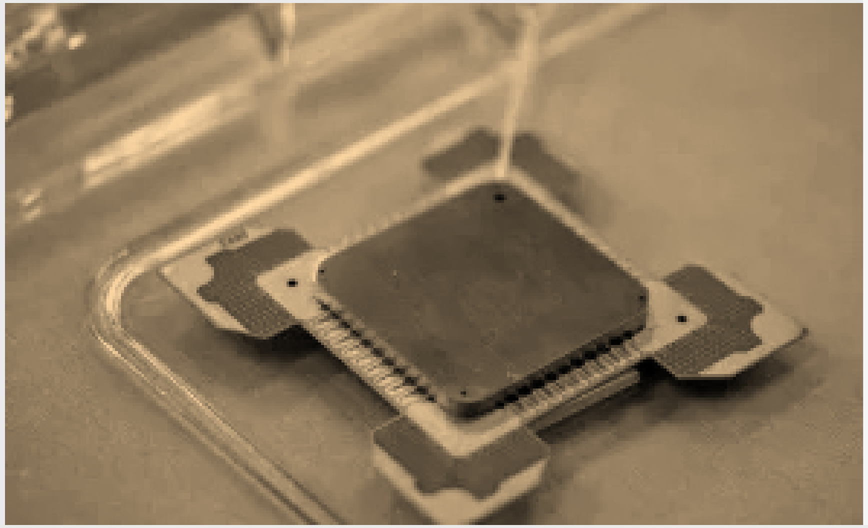
Linkages and dependencies

Interdependency

The technical development paths of quantum computing, quantum communication and quantum sensing are highly interdependent with advancements in one area often facilitating or becoming necessary for progress in another over the next decade. For instance, new calibration and simulation techniques from quantum computing can enhance sensor performance while robust sensing hardware can inform the design of qubits. Additionally, error-correction schemes developed in computing support long-range quantum communication links, and high-quality entanglement distribution facilitates the modular scaling of quantum processors.

Shared enablers

Advances in on-chip photonic circuits (for the manipulation, routing and detection of photons) and in compact automated cryogenic platforms provide the physical backbone for superconducting qubits, single-photon communication links, and ultrasensitive sensors alike.



	Quantum Sensing	Quantum Computing	Quantum Communication
Quantum Sensing		Precision metrology underpins qubit fabrication and control • Microscopic hardware characterisation • Feedback into fabrication • Dynamic calibration loops • Millikelvin qubit readout	Innovations in sensor hardware, cryogenic single-photon detectors and ultra-low-noise readout electronics, improve quantum link performance • Detector efficiency • Adaptive channel monitoring • Decreased dark-count rate
Quantum Computing	ML-driven data-processing methods feed directly into sensor development • Variational-algorithm calibration • Real-time data analysis • Digital twins for design • Large-scale entanglement for improved sensitivity		Error-correction and logical-qubit methods inform scalable repeater architectures • Architecture blueprints • Software stacks
Quantum Communication	Precise network timing and low-loss photonic links enable large-area, distributing entanglement across different locations and using that to improve performance • QKD-derived sync pulses • Shared cryo-detector modules	High-quality entanglement distribution and synchronisation enable modular quantum computers • Entanglement backbones • Photon-mediated gates • Secure channels	

TABLE:
These six cross-domain dependencies illustrate how advances in one quantum technology directly accelerate the others.

Shared approach and mindset are essential for success

Continuous learning

Fostering continuous learning through experimentation and early demonstrations aligns with calls for open innovation and agile R&D environments. Facilitating learning within Finland's tightly knit national quantum ecosystem enables confident progress absorbing lessons from early experiments, scaling what works, and staying nimble. Accelerating practical solutions requires broader end-user involvement from commercial and vital public sectors.

Hybrid solutions

Hybrid quantum-classical solutions blend traditional and modern learning methods. Quantum technologies complement classical systems offering advantages in computation, secure communication and precise sensing. This integration facilitates early exploration of quantum advantages laying the groundwork for practical applications that will inherently rely on sustained hybrid quantum-classical interactions. Its accessible software layer also provides significant avenues for traditional IT experts enabling scalable development despite talent scarcity.

Evidence-based monitoring

Both the quantum technology strategy and the roadmap reject the illusion of certainty. They recognise that quantum breakthroughs cannot be scheduled but they can be prepared for. Finland remains a trusted and capable partner in the international quantum landscape through evidence-based monitoring: not just of progress but also of emerging trends, disruptions and geopolitical shifts that could influence our positioning in quantum technology development.

Cross-domains and -competences

The integration enables breakthroughs in areas like quantum sensing to drive progress in fields such as secure communication and hybrid AI-quantum analytics. This cross-domain synergy extends to broader scientific engagement inviting diverse disciplines beyond physics. Such interdisciplinary collaboration is vital for mutual learning on future possibilities and for accelerating quantum development through contributions, such as novel materials. The synergy and skill development across sectors are crucial for both efficiency and long-term global competitiveness.

Realistic mindset

A realistic mindset, even with ambitious targets, is crucial for sustaining and balancing. While breakthroughs hold long-term promise, the short-term impact will likely emerge from narrower applications. Coupling ambitious goals with actionable plans developed in close collaboration with end-users is vital to manage expectations and cultivate sustained investment: thereby, mitigating the risks of a 'quantum winter'. Unexpectedly, and even with delays, modest advances can bring significant value and act as steppingstones toward a broader impact.

Accessible systems

As systems grow in complexity the roadmap highlights the need to integrate security from the outset and to develop technical and practical solutions in close collaboration that can scale over time. This will also require new thinking, abstractions and programming models, as well as robust security measures to make quantum systems safe, responsible and accessible to a broader range of developers and users.

6

Enablers for actionable roadmap

Foundational infrastructures for quantum technology development

Infrastructures are critical for the development, testing and early-stage experimentation of quantum technologies covering computing, communication, and sensing from both hardware and software perspectives. Pilot lines have spurred technological progress, as evident in VTT's quantum computers and the EU-collaborative quantum supercomputer platforms. **The following key infrastructures provide a framework for these activities and moreover, new initiatives frequently emerge to boost research-industry co-development:**

OtaNano (Aalto University & VTT)

Cleanroom infrastructure for micro- and nanofabrication, imaging and cryogenic testing. OtaNano comprises the Low Temperature Laboratory, Micronova, and the Nanomicroscopy Center. Supports design, prototyping and characterisation of quantum devices

Kvanttinova (operational ~2027)

Innovation hub and pilot line for quantum hardware (complement for OtaNano). Offers mid-scale fabrication, integration and pilot production services for emerging quantum devices.

FiQCI

National computing cluster linking academia, research centres and industry.
Enables hybrid quantum–HPC workflows by providing access to LUMI and Finland's quantum processors for algorithm development and benchmarking.

CSC AI Factory

AI-HPC platform co-located with LUMI and national research networks.
Facilitates large-scale quantum/classical simulations, quantum software testing and exploration of AI-driven quantum workflows. Through EuroHPC collaboration Finnish users will have access to a wide range of different quantum computers.

Nanoscience Center (University of Jyväskylä)

A nanotechnology hub, shared between physicists, chemists and biologists with wide range of activities. Has specialised fabrication and measurement facilities for silicon-based quantum technologies. Houses an open access private-public measurement facility focused on semiconductor-based spin qubit characterisation.

Finlight

National Competence Center offers access to photonics infrastructure across Finland. It supports quantum technology by providing characterisation and prototyping services for photonic components.

RDI activities and funding

Finnish national initiatives to build quantum expertise

Research projects and pilot lines are critical mechanisms through which basic research, applied research, and industry actors jointly implement the quantum roadmap. Finland's quantum ecosystem has evolved over the past few decades relying on robust academic research and national initiatives. The Finnish Quantum Flagship (FQF) (2024-2031) aims to develop new artificial quantum materials, advanced devices, sensors, and algorithms, along with exploring emerging technologies, building on the Quantum Technology Finland (QTF) Centre of Excellence (concluded 2025). The new Centre of Excellence on Quantum Materials (QMAT, 2026–2033) further strengthens Finland's quantum research base. The Quantum Doctoral Pilot Programme (2024-2027), part of the FQF, aims to train future quantum specialists and boost PhD involvement in the private sector. Alongside the FQF the PREIN flagship focuses on photonics and also supports the quantum industry by promoting the use of photonics in quantum technologies.

Business Finland's Quantum Computing campaign (2023–2025) played a key role in advancing the growth and internationalisation of Finland's quantum ecosystem focusing on software development and experimentation while uniting businesses and researchers. In addition to these public funding instruments companies, especially startups, which essentially constitute the sector's actors, require private investors to achieve ambitious goals.

European funding and collaboration for quantum capabilities

The Quantum Europe Strategy (2025) aims to make Europe a global leader by 2030. The European Quantum Flagship programme (2018-) supports research and innovation in quantum computing, communication and sensing. Finnish actors are involved in several major EU projects e.g., VTT leads the SUPREME consortium building on earlier pilot-line collaborations to expand Finland's capabilities with 300 mm wafer process design kits and 3D integration methods for superconducting qubit chips. The EU will also harmonise quantum development through its funding encouraging hubs to focus and specialise.

Key EU initiatives include:
- EuroHPC Joint Undertaking will deploy quantum computing systems across Europe aiming for 100 error-corrected qubits per system by 2030 and thousands by 2035 prioritising EU-based providers.
- European Quantum Communication Infrastructure develops secure quantum communication with terrestrial and satellite segments. Finland contributes through national QKD development and testing.
- Chips Joint Undertaking launches six quantum pilot lines in 2025 to accelerate prototyping and industrialisation.

Balancing competition and collaboration

The dual-use nature and export-control restrictions influence the development of quantum technologies necessitating careful consideration of collaboration partners. International collaboration and research with like-minded countries, including the US, Japan, Korea, Australia, and the UK, are crucial. However, this must also be balanced with intense global competition for private investments. The US receives over 50% of global private quantum funding, compared to Europe's 5%.

Nordic cooperation

The Nordic dimension further enhances efforts. A May 2025 joint statement by Nordic prime ministers and heads of government emphasises deeper regional cooperation for global quantum competitiveness. Two pilot projects have started: a pre-incubation programme bridging research and entrepreneurship, and an initiative applying quantum technologies to strengthen critical infrastructure resilience.

Future programme structures

Finland's Quantum Technology Strategy 2025-2035 identifies the necessity of a long-term national RDI programme. This RDI programme will connect technology developers and researchers with end-users, fostering collaboration and signalling investment opportunities in Finland. The EU quantum strategy also describes new initiatives across all three technology areas with specific themes to be refined with the Quantum Act in 2026. According to the EU quantum strategy, the focus will increasingly shift from basic research towards users and use cases. In addition to national and EU-level initiatives, various bilateral and multilateral collaborations exist between specific countries. Bilateral Memoranda of Understanding (MOUs) between countries can either create or limit opportunities in this changing landscape. To succeed, Finland needs both broad open calls to strengthen the ecosystem and major targeted funding for established spearheads alongside IP transfer and incubation activities within excellence centres.

- Research programmes are broadening their focus to include quantum computing, quantum communication and quantum sensing to advance quantum technology. (e.g., EuroHPC JU).
- To prevent overlapping development and resource allocation, there is a trend toward increasing specialisation among quantum hubs. (EU & Nordic).
- Increased end-user involvement and real-world applications should drive progress in quantum technology showcasing practical advancements for funders. (e.g., EU).

Roadmap co-creation process

This roadmap was co-created with the quantum community

Members of InstituteQ and Business Finland co-created the roadmap with a wide range of stakeholders through VTT facilitated process (see next page for contributors). Co-creation not only ensures multifaceted roadmap by diverse experts but also commits participants to next steps ideation and activation.

From the content perspective the transparent process and related facilitation aimed at both-and input including research and business, future potential and current hinders of development, and overall goals and individual technology elements. In other words, rather than dictating specific technology paths or prioritising individual use cases, the roadmap

- clarifies technology enabled development pathways.
- integrates the development of different technology domains.
- helps to identify (and ideate) feasible entry points and support mechanisms for adoption: scaling and integrating quantum technologies already with existing systems.
- enables mechanisms for monitoring progress, drivers and potential disruptions, and response to emerging technological opportunities and global developments.
- addresses key enablers for actionable next steps and successful execution for Finland.
- requires multidisciplinary collaboration, open knowledge sharing and ecosystem-wide learning across academia, industry and the public sector nationally and internationally.

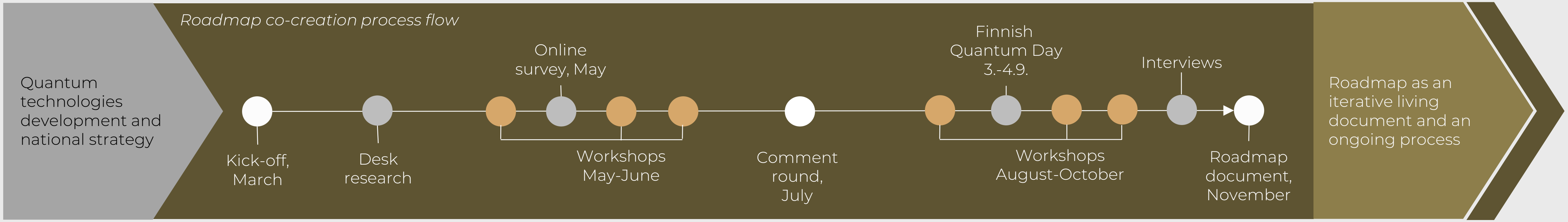
The roadmap is both a compass and a catalyst

Roadmap sets the direction and creates the conditions for Finland to become a leader and beneficiary in the quantum era. Its purpose and value become real only if it now triggers the following:

- Aligning stakeholders: The roadmap brings together researchers, companies, funders, policymakers, and the public ensuring everyone works toward shared goals and understands their roles.
- Accelerating progress: By identifying key technology gaps, opportunities and dependencies, the roadmap helps focus resources and investments where they will have the most impact.
- Focusing on real-world Impact: It prioritises pilots, demonstrations and early applications that deliver tangible value to society, industry and the economy.
- Reducing uncertainty: It provides a realistic evidence-based framework for monitoring progress, anticipating disruptions, and adapting to new developments in a rapidly evolving field.
- Maintaining flexible and adaptive: It is regularly updated based on new evidence, technological advances and stakeholder feedback allowing for course corrections as needed.

Roadmap co-creation process in numbers

Lead time (months)	*Workshops*	*Individual input*	*Conference days*	*Versions*
9	**6**	**52**	**2**	**4**



Contributors and sources

This roadmap draft is based on the following sources:

- Finland's National Quantum Technology Strategy 2025-2035 and selected sources detailed on the right-hand side.
- Insights from the working group especially during workshops and first roadmap version comments. Thank you for the commitment, contribution and active discussion: Outi Keski-Äijö (Business Finland), Aki Ylönen (Business Finland), Matti Palomäki (InnoQ/VTT), Jukka Nurminen (University of Helsinki), Kimmo Luoma (University of Turku), Teemu Hakkarainen (University of Tampere), Juha Muhonen (University of Jyväskylä), Matti Silveri (University of Oulu), Mikael Johansson (CSC), Urpo Kaila (CSC), Andrey Generalov (VTT), Sara Puorjamal (VTT)
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- Input from Finnish Quantum Day conference participants in September 2025.
- A survey conducted in May 2025 to gather community perspectives on the roadmap's content. The open survey for the community received 29 responses from individuals representing quantum-related companies, universities and research institutions.
- Information from the Quantum Flagship SRIA and QuIC SIR, scientific papers on quantum technology development, Finnish-authored research highlighting key focus areas, and plans from national research projects.

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ChatGPT, Gemini, Notebook LM and Copilot have been used for the purposes of summary, synthesis and idea generation with human reviews according to contributors listed above.

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Pictures in this document: vttresearch.com

Let’s realise the roadmap together!

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