White Paper: Nordic Quantum

This White Paper describes vision, purpose and strategic actions for Nordic Quantum, a network for quantum technology activities in Denmark, Finland, Norway and Sweden. It is based on four meetings of mainly academic quantum community in these countries, and compilation of data and background material during 2022-2023.

Executive summary

The Nordic Quantum network has the ambition to present itself as a global player in quantum technology, while maintaining a close dialogue with other partners both within Europe and outside. This goal will be achieved by establishing a common vision of quantum technology between institutions in Denmark, Finland, Norway, Sweden (and potentially Iceland), strengthening the coordination of activities in the field. Nordic Quantum should be seen from the outside as a world-leading initiative in quantum science and technology, representing a first-tier partner for academic and business activities in the field.

Background and existing strengths

The Nordic academic community has recently identified the need and opportunity to build an umbrella, to reach higher visibility and facilitate collaboration in the growingly competitive field of quantum science and technology (QST). The community has organized four meetings to review and build on top of the Nordic expertise and strengths in QST, September 2022 in Helsinki, March 2023 in Brussels, September 2023 in Stockholm, and May 2024 in Copenhagen. In tandem, reinforcing the Nordic openness and willingness to collaborate in this area, the Nordic Quantum Life Science Round Table has convened in Sweden 2021, Denmark 2022, Finland 2023 and coming up in Norway, September 2024. More recently, a Nordic Group for standardization of quantum technologies was initiated.

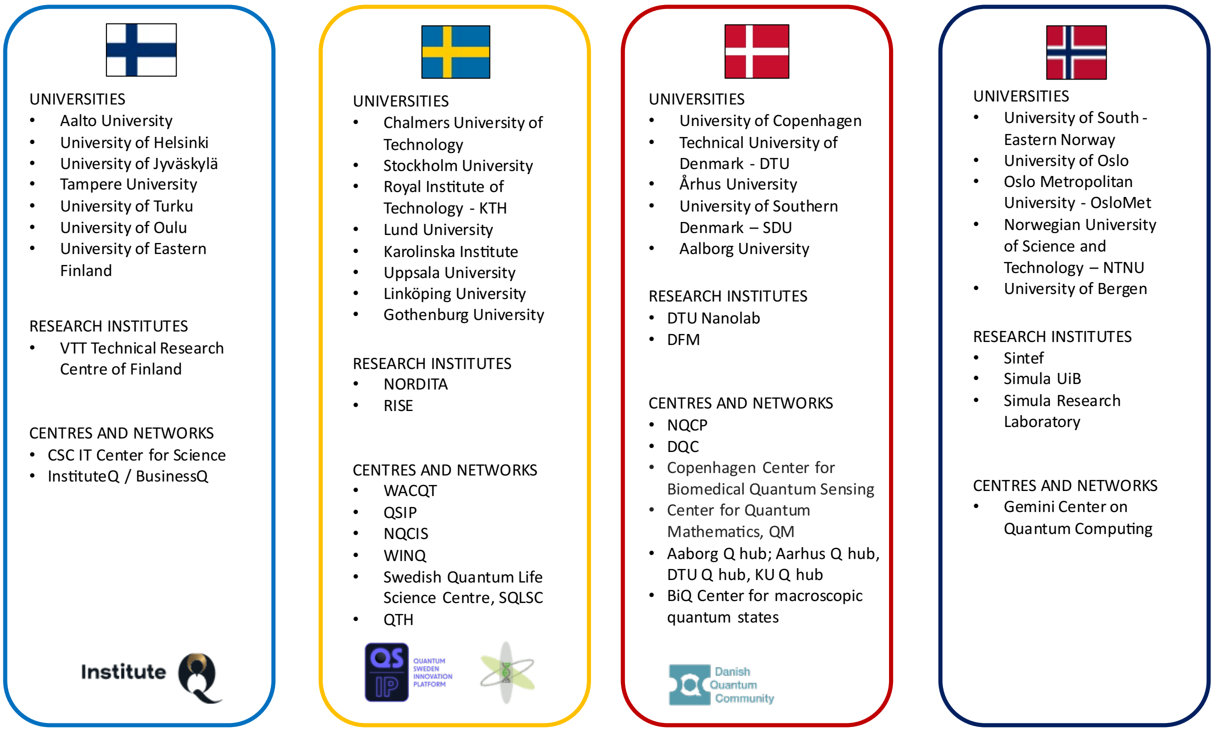


Figure 1. Nordic universities, research and technology organizations and centres with activities in quantum science and technology (non-exhaustive).

The community builds around a very strong, existing basis in quantum science and technology. This involves 24 universities, 6 research and technology organisations, and several centres with activities in quantum science and technology (see Figure 1 and Annex 2). The Nordic industrial ecosystem (see Figure 2) currently involves over approximately 90 companies (in January 2024).

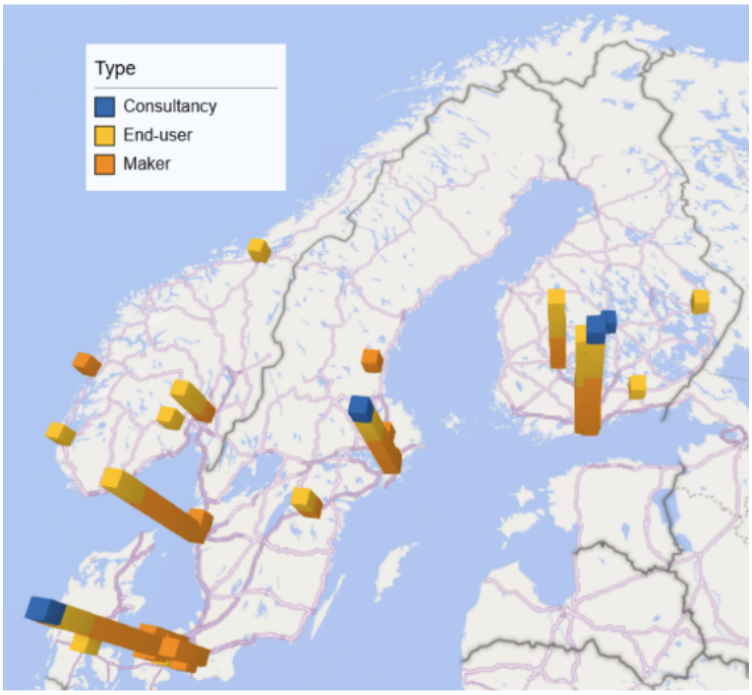


Figure 2. Geographic distribution of Nordic industries with activities in quantum science and technology. "End-user" in this case implies that they mainly have shown interest in QST but not necessarily yet have any commercial products or services based on QST. "Maker" covers all four quantum technology pillars. They together cover many parts of their respective value chains, see also Annex 1 (for a list of companies).

The strengths of the Nordic quantum community include:

- Worldwide-recognized research groups and industry, for example, three out of the twelve key countries around the International Roundtable on Quantum Information (https://www.quantum.gov/readout-international-roundtable-2n/) are Nordic (DK, FI, SE)
- A strong existing QST community with expertise along the full quantum technologies stack: quantum fundamentals (quantum phenomena, materials science, device fabrication and quantum information), quantum sensing and metrology, simulation and computing, and quantum communication (for a full mapping, see Annex 2)
- Excellent open-access infrastructures and infra-networks for the development and use of quantum technologies, e.g., Myfab (SE), OtaNano and FiQCI (FI), Norfab (NO), Nanolab (DK) (including expansion under development for quantum test and fabrication facilities), and Kvanttinova (FI) (fabrication facilities for industrial scale-up)
- Industry interest and strong industry-academia networks: BusinessQ (FI), QSIP (SE), DQC (DK)
- An increasing number of spinouts and start-up activities
- Highly valued education systems and emerging educational efforts in QST, see Annex 3
- Excellent innovation systems: the Nordics lead the European Innovation Scoreboard (EIS)[1] and are among the top ten in the Global Innovation Index (GII)[2]
- A high potential to retain scientific talent

Additionally, there is a long and fruitful history of bilateral collaborations between many laboratories and institutions in the Nordics; Nordic countries share similar operational cultures and values, and a complementarity of strong research backgrounds can be identified. This provides a fruitful basis for synergistic

[1] https://ec.europa.eu/research-and-innovation/en/statistics/performance-indicators/european-innovation-scoreboard/eis
Specifically, Sweden, Finland and Denmark rank among the top-3 EU countries in EIS overall innovation score, the top-4 EU countries in PCT patent applications, the top-5 EU countries in top-10% cited scientific publications, and the top-6 EU countries in venture capital expenditure.
[2] https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2023-section1-en-gii-2023-at-a-glance-global-innovation-index-2023.pdf

Nordic efforts in the growingly competitive field of QST. A joint Nordic SWOT analysis was prepared as part of the Nordic community meetings, see Annex 4.

Vision

Our vision is for the Nordic region to become the world's most attractive regional ecosystem in quantum technology, renowned for having the most quantum literate workforce in the world.

Purpose and aims

The purpose of forming the Nordic Quantum network is to strengthen the Nordic region as a global hot spot for quantum science, technology, and education. Our overall aim is to:

- Further strengthen the quality of Nordic scientific activities
- Provide and develop the Nordic educational framework specific to QST workforce
- Actively engage in outreach programs, aiming at the "quantum literacy" of society at large
- Promote innovation and further increase the region's attractiveness to businesses
- Coordinate already existing activities in the Nordics and act as a catalyst for new initiatives
- Facilitate an ecosystem that attracts and retains talent by offering an expanding number of opportunities for experts and young talents to move forward in this field within the Nordics
- Encourage common and adaptive Nordic policies and strategic actions to provide clear operational framework in Nordics

Required actions

To achieve the above vision, we have identified a need for joint efforts in following areas:

Research, education and training

- Enhance scientific and educational collaboration between our countries, including consolidating pre-existing joint initiatives, for example:
  - develop Nordic visiting researchers' and lecturers' schemes (including visiting professorships)
  - establish Nordic doctoral training networks and industry-academia doctoral exchange programs (model: WACQT)
  - enable shared recruitment of postdocs between laboratories
  - organize Nordic summer and winter schools
- Support workforce development and increase quantum literacy in the Nordic region, for example:
  - develop Nordic trainings for targeted workforce and industry
  - catalyse Nordic quantum ecosystem boost (model: BusinessQ)
  - facilitate common advertising of Nordic (junior) positions both within the Nordics and for candidates coming from other countries
  - investigate opportunities for shared Nordic e-Infrastructures (example: Nordic-Estonian Quantum Computing e-infrastructure NordiQuest)

Investments and strategic resourcing

- Identify and promote funding opportunities for supporting national and Nordic collaboration in quantum technology
- Promote a coordinated Nordic strategy towards the EU (government action)
- Secure re-investment and running support for critical infrastructure (Myfab, OtaNano, DTU Nanolab, ...)
- Secure a Nordic advantage in major international efforts, such as the European Quantum Pact, European Chips Act (competence centres, infrastructure funding), and NATO programs

Communication

- Implement a Nordic visibility campaign to attract strong and diverse students and workforce
- Increase awareness and understanding of opportunities and risks of quantum technology
- Raise awareness of and lower the threshold to use the Nordic infrastructure for QST

Nordic Quantum coordination

- Assign a full-time coordinator for Nordic Quantum to support the activities of the consortium, such as the organization of the meetings, outreach activity and communication campaign
- Organize Nordic Quantum meetings 1-2 times a year; these meetings will allow the consortium to discuss its status and development
- Organize outreach meetings once a year, which will be aimed at involving other stakeholders (industry and policymakers) in the discourse around QST; one of the Nordic Quantum meetings each year can be reserved for this purpose
- Participate in the international (non-Nordic) dialogue in the field of QST

Securing seed funding for such basic coordination and meeting activities will be critical for Nordic Quantum.

Conclusion

Nordic players in quantum science and technology have the capability and ambition to develop a Nordic synergy that would allow the region to maximize its impact both at the European level and on the global scene. Nordic Quantum has a high potential to act as a catalyst for a growth process, from which the whole Nordic region can benefit. In the global landscape, each Nordic country alone is a minor player, while the most prominent role is played by the United States, China and, especially concerning academia, by EU countries. Joining forces will give a stronger voice to the Nordic countries and back independent Nordic actors operating in an international context. Nordic Quantum has a high potential to grow into a powerful strategic alliance that pools critical knowledge and resources to address global quantum challenges. Determined actions can make the Nordic region the preferred partner for academic exchange and investment in quantum technologies.

Annex 1. Companies active in the Nordic region with interest in quantum technologies

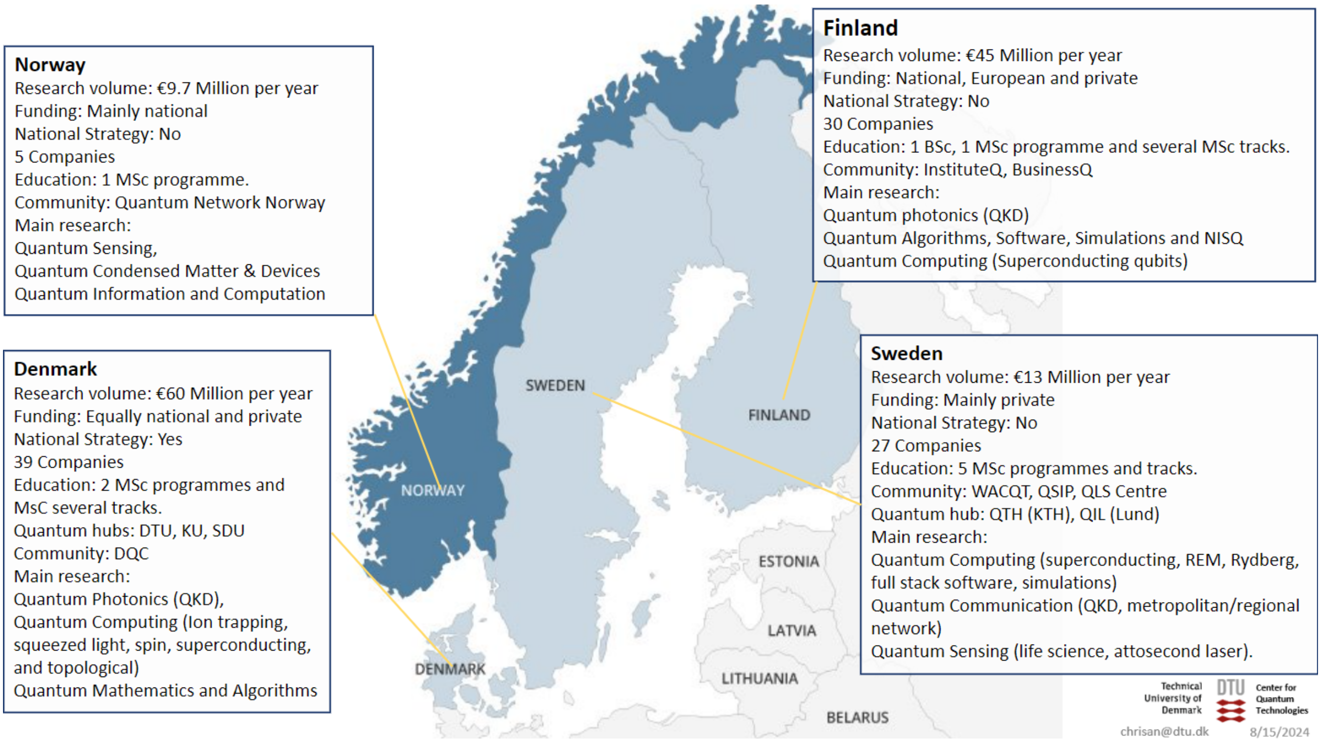
Companies are mostly either makers or users of quantum technology, in a few cases consultants.

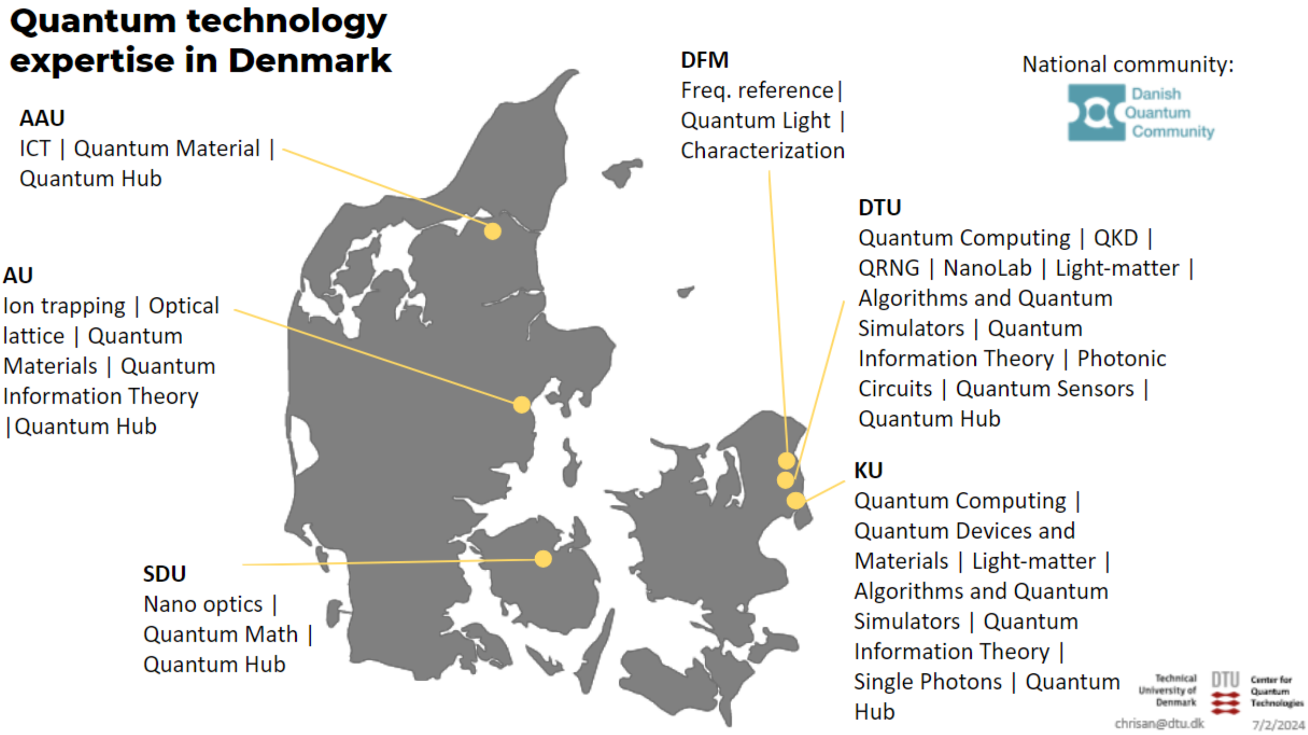
Name	QT Pillar	Type	Country
Alea Quantum Technologies	Communication	Maker	DK
Dencrypt	Communication	Maker	DK
Partisia Quantum	Communication	Maker	DK
Celare Quantum Communications	Communication	Maker	DK
Vaisto Solutions Oy	Communication	Maker	FI
QuCertify AB	Communication	Maker	SE
Cryptomathic A/S	Communication	User	DK
TDC NET	Communication	User	DK
Nokia	Communication	User	FI
Unikie Oy	Communication	User	FI
Ericsson	Communication	User	SE
Hitachi Power Grids Sweden AB	Communication	User	SE
Huawei Technologies Sweden AB	Communication	User	SE
Maybell Quantum Industries Aps	Computer	Maker	DK
Quantum Machines	Computer	Maker	DK
Quantum Foundry Copenhagen	Computer	Maker	DK
Atom Computing Denmark	Computer	Maker	DK
Riverlane	Computer	Maker	DK
Terra Quantum GmbH Finland	Computer	Maker	FI
IQM	Computer	Maker	FI
Quantastica	Computer	Maker	FI
QuantrolOx Finland Oy	Computer	Maker	FI
SemiQon	Computer	Maker	FI
Atlantic Quantum AB	Computer	Maker	SE
Labber Quantum	Computer	Maker	SE
Low Noise Factory	Computer	Maker	SE
Quantum and Classical Solutions AB	Computer	Maker	SE
Robert Anna Rehammar AB	Computer	Maker	SE
ScalinQ AB	Computer	Maker	SE
Sweden Quantum AB	Computer	Maker	SE
CSC IT Center for Science Ltd	Computer	User	FI
Sigma2	Computer	User	NO
QplayLearn	Education	Maker	FI
Phase Space Computing	Education	Maker	SE
IdesmaTech	Enabler	Consultancy	DK
Accelink Denmark A/S	Enabler	Maker	DK
ATLANT 3D Nanosystems	Enabler	Maker	DK
Beamfox Technologies Aps	Enabler	Maker	DK
FOM Technologies	Enabler	Maker	DK
Mellanox Technologies Denmark ApS	Enabler	Maker	DK
Microsoft Development Copenhagen	Enabler	Maker	DK
NKT Photonics	Enabler	Maker	DK
Norblis ApS	Enabler	Maker	DK
Qdevil ApS	Enabler	Maker	DK
SiPhotonIC Technologies	Enabler	Maker	DK

Sparrow Quantum	Enabler	Maker	DK
Stensborg	Enabler	Maker	DK
Zybersafe Aps	Enabler	Maker	DK
Aivon Oy	Enabler	Maker	FI
Beneq Oy	Enabler	Maker	FI
Bluefors Oy	Enabler	Maker	FI
Modulight Corp	Enabler	Maker	FI
Okmetic	Enabler	Maker	FI
Picosun Oy	Enabler	Maker	FI
Vexlum Oy	Enabler	Maker	FI
Adamant Quanta	Enabler	Maker	SE
ConScience AB	Enabler	Maker	SE
Iloomina	Enabler	Maker	SE
Intermodulation Products	Enabler	Maker	SE
MB Scientific AB	Enabler	Maker	SE
Svenska Laserfabriken AB	Enabler	Maker	SE
Lightnovo APS	Sensing	Maker	DK
DiaSense	Sensing	Maker	DK
Qfacotry	Sensing	Maker	DK
See through solutions	Sensing	Maker	FI
Deep Light Vision AB	Sensing	Maker	SE
Quantum Scopes AB	Sensing	Maker	SE
Single Photon Quantum Radiology AB	Sensing	Maker	SE
SpectraCure AB	Sensing	Maker	SE
SAAB	Sensing	User	SE
Kvantify Aps	Simulation	Maker	DK
Molecular Quantum Solutions ApS	Simulation	Maker	DK
Classiq Technologies	Simulation	Maker	DK
QUNASYS Denmark	Simulation	Maker	DK
Sqale	Simulation	Maker	DK
Qool	Simulation	Maker	DK
Algorithmiq	Simulation	Maker	FI
Danske Bank	Simulation	User	DK
Frogne	Simulation	User	DK
Örsted Wind Power	Simulation	User	DK
Cargotec Finland Oy	Simulation	User	FI
Kouvola Innovation Oy	Simulation	User	FI
Mantsinen Grouo Ltd Oy	Simulation	User	FI
Metsa Fibre Oy	Simulation	User	FI
OP Pohjola	Simulation	User	FI
Quanscient	Simulation	Maker	FI
Rovio	Simulation	User	FI
SILO AI	Simulation	User	FI
DNB	Simulation	User	NO
Equinor	Simulation	User	NO
Kongsberg Group	Simulation/Sensing	User	NO
Ruter	Simulation	User	NO
AstraZeneca	Simulation	User	SE
Jeppesen	Simulation	User	SE

Volvo Group	Simulation	User	SE
Qpurpose	Simulation	Maker	DK
KPMG P/S		Consultancy	DK
Reaktor		Consultancy	FI
Unitary Zero Space		Consultancy	FI
Predli Emerging Tech Consulting		Consultancy	SE
Atos		User	FI

Annex 2. Map of expertise in quantum science and technology in the Nordic countries





Quantum technology expertise in Finland

InstituteQ members

Tampere University
Novel quantum materials and metamaterials | Quantum emitters and lasers | Quantum photonics | Theory of quantum many-body systems

CSC
Hybrid high-performance computing and quantum computing infrastructure (HPC+QC) | Deployment of QKD in Finland

University of Turku
Quantum foundations | Optical methods

Aalto University
Superconducting technologies | Quantum materials | Integrated quantum photonics | Sensing applications | Quantum computers | Algorithms and software | Quantum communications engineering | Quantum foundations | Market emergence

University of Oulu
Quantum simulations | Cybersecurity Quantum error correction | Molecular qudits | NV-centers

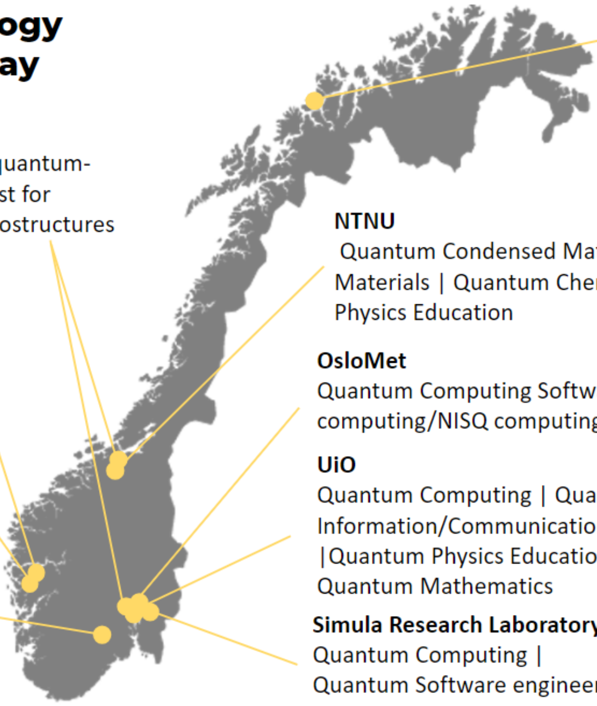
University of Jyväskylä
Superconducting circuits | Quantum materials | Radiation sensors | Quantum algorithms and software | Precision measurements | Atomic clocks | Quantum photonics

University of Eastern Finland
Micro- and nanodiamond synthesis | Quantum-enhanced electromagnetic measurements | Quantum photonics

University of Helsinki
Quantum algorithms and software | Quantum simulations and NISQ | Quantum information and foundations | Quantum education research | Quantum philosophy

VTT
Microsystems design and fabrication | Quantum components and architectures | System integration | Quantum computers | Quantum standards, and atomic clocks | Deployment of QKD in Finland

Quantum technology expertise in Norway



SINTEF
Quantum Computing | Hybrid quantum-classical algorithms | NordIQuEst for Nordic HPC Infrastructure| Nanostructures

Simula UiB
Post Quantum Cryptography

UiB
Quantum Computing | Quantum Sensing

USN
Quantum Computing | Quantum Optomechanics | Quantum Sensing | Micromechanical oscillators | Nanotechnology

UiT
Quantum Chemistry

NTNU
Quantum Condensed Matter Physics | Quantum Materials | Quantum Chemistry | Quantum Physics Education

OsloMet
Quantum Computing Software | Open quantum computing/NISQ computing | Quantum Education

UiO
Quantum Computing | Quantum Information/Communication | Quantum Chemistry |Quantum Physics Education | Quantum materials | Quantum Mathematics

Simula Research Laboratory
Quantum Computing | Quantum Software engineering | NordiQuEst

Quantum technology expertise in Sweden

WACQT members

LiU
Solid State Quantum Systems |Quantum Materials | Quantum Cryptography | Quantum Communication | Quantum Sensing

CTH
Superconducting Quantum Computing | Quantum Information | CV | Quantum Sensing | Quantum Simulation | Topological Quantum Technologies

GU
Quantum Error Correction

LU
Quantum Computing | Quantum Communications | Quantum Metrology |Quantum Dots | Nanowires | Attosecond laser | Laser spectroscopy of negative ions

UU
Quantum Computing | Quantum Communications with multidimensional qubits | Quantum Simulation | Quantum Materials

KI
Quantum Sensing

KTH / Nordita
Quantum Computing | Quantum Communications |QCI Node | Quantum Sensing | Quantum Simulation | Quantum Chemistry | Quantum Materials | Quantum Technology Hub

SU
Quantum Computing with ion traps | Quantum Communications with multidimensional qubits | Quantum Sensing | Quantum Simulation | Quantum Field Theory |Quantum Chemistry

Technical University of Denmark DTU Center for Quantum Technologies
chrisan@dtu.dk 8/13/2024

Annex 3. Formal quantum science and technology education in the Nordics

Denmark

University of Copenhagen/DTU, Master of Science in Quantum Information Science (joint program)
Webpage: https://studies.ku.dk/masters/quantum-information-science/
https://www.dtu.dk/english/education/graduate/msc-programs/quantum-information-science
Duration: 2 years

Description: The MSc in Quantum Information Science (120 ECTS) is a program offered jointly between University of Copenhagen (UCPH) and the Technical University of Denmark (DTU). During the first semester the students follow courses at UCPH. During the second semester the students follow courses at DTU. In the second year of the program one can choose courses at either university.

The curriculum consists of three compulsory courses and a range of restricted elective courses within Quantum Information Theory (UCPH), Physical Implementation of Quantum Information Processing (UCPH), Experimental Techniques in Quantum Technology (DTU), Quantum Compilers (DTU), and Quantum Algorithms and Machine Learning (DTU). One can also select between a wide range of elective courses which specialize in aspects of computer science, mathematics or physics.

Aarhus University, Erasmus Mundus Master in Quantum Technologies and Engineering
Webpage: https://www.quanteem.eu/
Duration: 2 years

Description: The Erasmus Mundus Master in Quantum Technologies and Engineering (QuanTEEM) is a diploma of excellence funded by the Erasmus+ program of the European Union and supported by the collaboration between 3 international universities: Université Bourgogne Franche-Comté (operated at Université de Bourgogne), the Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau and Aarhus University. In addition, the QuanTEEM consortium has more than 20 associated partners, including 13 industrial partners ranging from large companies to Quantum startups.

The program is based on the established quantum pillars: quantum communication, quantum simulations, quantum sensing, quantum computers and computation, and quantum information sciences, towards innovation. It addresses aspects and applications ranging from basic research in physics and beyond to major grand challenges such as energy, materials, health, security and environment, to which quantum technologies have started to apply. The specialization of Aarhus University consists of platforms for quantum technologies.

University of Southern Denmark, Master of Science in Quantum Computing
Duration: 2 years

The education will enrol its first batch of students summer 2025

Technical University of Denmark, Quantum Engineering – Study Line at Engineering Physics

Webpage: https://www.dtu.dk/english/education/graduate/msc-programmes/engineering-physics/study-lines/quantum-engineering

Duration: 2 years

Description: The study line in quantum engineering focuses on the understanding, control and design of complex quantum systems for applications in emerging quantum technologies such as extremely sensitive sensors, quantum communication systems and quantum computers. The methods involved range from quantum mechanical calculations and simulations to the theoretical and experimental development and investigations of optical systems, solid-state systems, and electronic systems designed to harness the fundamental properties of quantum mechanics – such as quantum superposition and entanglement.

Technical University of Denmark, Quantum Engineering – Study Line at Engineering Light

Webpage: https://www.dtu.dk/english/education/graduate/msc-programmes/engineering-light/study-lines/quantum-photonics

Duration: 2 years

Description: Quantum Photonics is a thriving research field that embraces quantum physics, nanotechnology and important applications. These years we witness the transfer from research labs to the industry of innovative and valuable technologies, while others still require decades of fundamental research. This technological specialization is set up to address these challenges and has three main objectives:
1. To prepare the student for the quantum photonics technology of tomorrow, as applied, e.g., in quantum simulators, quantum computers and the quantum internet.
2. To equip the student with basic and advanced knowledge about the physics and the technology of the platform (e.g., nanophotonics, quantum optics, quantum photonic communication).
3. To give the student hands-on experience with advanced nanofabrication & the key experiments that reveal the nature of quantum photonics (e.g., quantum light source, two-photon interference, quantum entanglement).

University of Copenhagen, Quantum Physics – Study Line at Physics

Webpage: https://studies.ku.dk/masters/physics/programme-structure/?acc=quantum

Duration: 2 years

Description: In quantum physics, you study the fascinating world of physics ranging from the small scales of elementary particles to the vast dimensions of the universe.
The high-ranking quantum physics programme at The Niels Bohr Institute provides you with knowledge and skills to describe space-time and elementary particles as well as macroscopic and microscopic phenomena in quantum and soft matter, and it prepares you to apply your knowledge in modern quantum technology.
The specialization begins with a course in advanced quantum mechanics. The course provides excellent opportunities for going deeper into a specific branch of physics.

Finland

Aalto University, Quantum Technology major in Bachelor of Science (Technology); Master of Science (Technology)

Webpage: https://www.aalto.fi/en/study-options/quantum-technology-bachelor-of-science-technology-master-of-science-technology; https://www.aalto.fi/en/programs/aalto-bachelors-program-in-science-and-technology/curriculum-2022-2024

Duration: 3+2 years

Description: The Bachelor's degree (180 ECTS) is composed of basic studies of the program (65 ECTS mathematics, programming, industrial engineering and management, obligatory languages, Aalto studies, orientation), the major in quantum technology (65 ECTS including BSc thesis and seminar), the minor (20-25 ECTS) and elective studies (25-30 ECTS). The compulsory courses introduce students to quantum science and technology, fundamental physics such as the quantum theory and electromagnetism, programming, the necessary analytical and numerical tools from mathematics, as well as key quantum technology topics such as quantum-electric circuits and quantum-information processing. The optional courses cover advanced topics in nanotechnology, quantum mechanics, photonics, materials, quantum computing, and quantum technology.

The Master's Program in Engineering Physics includes a major in materials physics and quantum technology, offered as a long major, and as a compact major. The compact major forms the core content for the long major. The pertaining courses cover important topics for engineering physics, and methods from computational, theoretical, and experimental physics. The compact major includes also some choices for more detailed focusing on a certain subject. The rest of the studies in the long major have a flexible structure and provide the student with the possibility of focusing on physics, nanoscience, or designing a more cross-disciplinary content for the long major.

Combining courses from Aalto University and the University of Helsinki is possible.

University of Helsinki, Quantum Science and Technology studies in several Master's programs
Webpage: https://www.helsinki.fi/en/researchgroups/instituteq-the-finnish-quantum-institute-university-of-helsinki/courses

Description: Students from many different Master's programs can freely combine from a wide list of courses to include in their studies. Combining courses from the University of Helsinki and Aalto University is possible.

Finnish Doctoral School in Quantum Technology
Webpage: https://instituteq.fi/instituteq-launches-doctoral-school/

Pre stage launched in 2023

Norway

University of Oslo, Master's Program in Physics, Materials, Nanophysics and Quantum Technology
Webpage: https://www.uio.no/english/studies/programs/physics-master/program-options/materials-nanophysics/index.html
Duration: 2 years

Description: The study program consists of theoretical curriculum and a Master's thesis. The program has specializations in low energy quantum phenomenon, structure physics, disordered and complex systems and semiconductor physics.

University of Oslo, BSc track in QST under the physics program, starting up fall 2024:

https://www.uio.no/studier/program/fysikk-astronomi/studieretninger/kvanteteknologi/

Sweden

Chalmers, Master's Programs in Physics and Nanotechnology, profile in Quantum Technology
Webpage: https://www.chalmers.se/en/education/find-masters-program/physics-msc/
https://www.chalmers.se/en/education/find-masters-program/nanotechnology-msc/
Duration: 2 years

Description: The Master's program (120 ECTS) in Physics is focused on theoretical, computational, and/or experimental aspects of physics. Topics include atomic simulations, Bayesian statistics, continuum modeling, electronic structure, excitons, machine learning, metamaterials, materials imaging, nanomaterials, plasmons, quantum computing, quantum field theory, quantum mechanics, quantum technology, and spectroscopy techniques. The program consists of compulsory courses, compulsory elective courses and elective courses.

The Master's program (120 ECTS) in Nanotechnology is focused on fundamental nanoscience and on the design and creation of components on the nanoscale. The subjects of physics, biology, chemistry, and technology of nanoscale systems are fundamental areas in the program. The courses handle topics such as nanomaterials chemistry, quantum technology and superconductivity. The program includes a profile track in quantum engineering.

KTH, Master's Program in Engineering Physics, Quantum Technology track
Webpage: https://www.kth.se/en/studies/master/engineering-physics/tracks/quantum-technology-1.927577
Duration: 2 years

Description: The Master's program (120 ECTS) in Engineering Physics bridges the gap between theoretical physics and practical engineering, seeking to develop future technology. Solving complex problems is an integral part of education, demanding in-depth knowledge of physics, as well as analytical and computational tools. Through specializations, students become domain experts in one field of physics and go on to advanced industrial R&D positions or PhD studies.

The Quantum Technology track focuses on engineering systems to manipulate and measure quantum states with applications in information processing, secure communication and sensing. A minimum of 40 ECTS credits must be taken from core knowledge courses within the track. Topics covered: quantum mechanics, entanglement, superposition, decoherence in open quantum systems, quantum information, quantum limited sensing, quantum non-destructive measurements, quantum communication, macroscopic quantum systems, quantum optics, quantum microwaves, quantum materials. A Master's degree project in academia or industry is included in the studies.

Stockholm University, Physics Master's Program, Quantum Matter track
Webpage: https://www.su.se/english/search-courses-and-programs/nfyso-quan-1.577821
Duration: 2 years

Description: The Physics Master's program offers a lot of freedom to choose courses. The Quantum Matter study path is geared towards corresponding emerging technologies with a combination of mandatory, eligible and optional courses. The track provides a solid base in analysis of data, experimental physics and experimental methodology. This is complemented by at least one theoretical course.

University of Uppsala, Master's Program in Quantum Technology
Webpage: https://www.uu.se/en/study/program/masters-program-quantum-technology
Duration: 2 years

Description: The Quantum Technology Master's program at Uppsala University prepares students for the emerging quantum revolution, where they gain expertise in optical, electronic, and magnetic quantum phenomena, applying them to advancing technologies. Students benefit from hands-on projects led by frontline quantum experts in an international environment with state-of-the-art facilities. The program is aimed to equip students for success in both academia and industry.

Linköping University, Master's Program in Materials Physics for Nano and Quantum Technology
Webpage: https://studieinfo.liu.se/en/program/6mmnq/5058#syllabus
Duration: 2 years

Description: The Master's program in Materials Physics for Nano and Quantum Technology aims to provide students with specialist knowledge in materials physics, nano and quantum technology and make the students highly competi-tive in this rapidly developing field. The program meets both the national and international needs of universities, industry, and society in general.

The program intends to provide an in-depth understanding in the physical processes and phenomenon laying the basis for advanced applications in materials science, and an understanding for the demand on sustainable materials in the strive for sustainable techniques. The program gives the students an understanding of the interaction between materials, technology and the surrounding society.

Lund University, Quantum Science and Technology – specialization in the Master's Programs in Engineering Physics and Physics
Webpage: https://www.fysik.lu.se/en/master-in-quantum-science-and-technology
Duration: 2 years

Description: The specialization in Quantum Science and Technology (120 ECTS) is available for students in the Engineering Physics program at the Engineering Faculty (starting 2024) as well as for students in the Physics Master's program at the Natural Science Faculty (starting 2025). The specialization gives deepened knowledge in fundamental quantum mechanics, as well as in applications such as quantum communication, quantum computing, and quantum sensing. Students can choose between a more theoretical or more experimental profile. The experimentally oriented courses focus either on quantum optics/photonics or on solid state/semiconductor quantum devices, both directions benefiting from the excellent experimental facilities hosted by Lund Laser Centre and NanoLund/Lund Nano Lab.

Swedish Graduate School in Quantum Technologies, Ph.D. program
Webpage: https://www.chalmers.se/en/centres/wacqt/graduate-school/
Duration: 4 years

Description: The objective of the Swedish Graduate School in Quantum Technologies is to foster the next generation of Swedish quantum researchers and quantum engineers. Over the duration of WACQT, the graduate school will fund 95 PhD studentships, of which at least 30 are industrial PhD students.

Annex 4. Joint Nordic SWOT analysis

Strengths	**Weaknesses**
• Excellent open-access infrastructures (Myfab in Sweden; VTT in Finland; Nanolab in Denmark) • Strong existing QST community with expertise along the full QST stack • Industry interest and strong industry-academia networks • Spinouts and start-up activities • Highly valued education systems • Nordic countries are high rankers in the European Innovation Scoreboard • Existing research infrastructure • Strong enabling-technologies industry • Strong focus on Quantum Life Science: NQCP (DK) and Swedish QLS Centre (SE)	• Lack of national coordination and strategies • Lack of critical mass • Low awareness and lack of competence in industry at potential end-users • Small number of long-term funding sources • Limited regional market • Lack of awareness for opportunities for students

Opportunities	**Threats**
• Nordic collaboration can give strength through collaboration, critical mass and international visibility • Coordinated government action • Quantum technology attracts strong and diverse students • Synergies with European Chips Act (competence centres, infrastructure funding...) • Collaboration with industry • Emerging national strategies to build on	• International competition for talent • Quantum winter • Lack of re-investment and running support for infrastructures

Annex 5. Persons endorsing this white paper

List of persons endorsing this White Paper at its first publication in August 2024. We trust more will be added in a separate list.

Name	Affiliation	Country
Are Magnus Bruaset	Simula Research Laboratory	Norway
Caterina Foti	Aalto University	Finland
David Havilland	KTH Royal Technical University	Sweden
Ebba Carbonnier	Karolinska Institutet	Sweden
Francesco Massel	University of South-Eastern Norway	Norway
Göran Johansson	Chalmers University of Technology	Sweden
Heiner Linke	Lunds University	Sweden
Jeroen Danon	Norwegian University of Science and Technology	Norway
Jill Miwa	Aarhus University	Denmark
Johan Veiga Benesch	Chalmers University of Technology	Sweden
Jukka Pekola	Aalto University	Finland
Justin Wells	University of Oslo	Norway
Katia Gallo	KTH Royal Institute of Technology	Sweden
Lydia Baril	Technical University of Denmark	Denmark
Martin Leijnse	Lund University	Sweden
Mikael Fogelström	Nordita	Sweden
Mikko Möttönen	Aalto University	Finland
Minna Günes	Aalto University	Finland
Mohamed Bourennane	Stockholm University	Sweden
Niels Gregersen	Technical University of Denmark	Denmark
Per Delsing	Chalmers University of Technology	Sweden
Pertti Hakonen	Aalto University	Finland
Peter Samuelsson	Lund University	Sweden
Sabrina Maniscalco	University of Helsinki and Aalto University	Finland
Sonia Coriani	Technical University of Denmark	Denmark
Stefan Kröll	Lund University	Sweden
Susanne Viefers	University of Oslo	Norway
Ulrik L. Andersen	Technical University of Denmark	Denmark
Andrei Manolescu	Reykjavik University	Iceland
Lárus Thorlacius	University of Iceland	Iceland
Sreenath K. Manikandan	Nordita	Sweden