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Quantum Europe Strategy: Quantum Europe in a Changing World

Quantum Europe in a changing world

1.1 Introduction

Europe is a quantum[1] continent. From iconic forerunners such as Max Planck, Albert Einstein Niels Bohr, and Erwin Schrödinger, to current day pioneers and Nobel Prize laureates like Theodor Haensch, Albert Fert, Serge Haroche, Anton Zeilinger, Alain Aspect and Anne L'Huillier, Europe has always been the place of quantum science.

Advances in quantum science represent some of the most transformative developments in technological history. The Draghi report[2] refers to quantum as "the next trailblazing innovation in the computing field, which could open new opportunities for the EU's industrial competitiveness and technological sovereignty".

Today we stand at an inflection point, as the global race to harness quantum technologies accelerates, moving beyond the labs and entering real-world applications. From Magnetic Resonance Imaging (MRI) scanners in healthcare and material advances in energy, to gravimeter sensors for geophysics and navigation, secure communications, and quantum computing solving complex problems in logistics and finance, these breakthroughs are beginning to reshape key industries and societal infrastructure.

Quantum technologies also have a dual-use potential[3] making them useful for both defence and national security applications, thus driving the strategic interest of major public and private players.

Against this background, the EU has identified quantum as a critical technology[4] in its Economic Security Strategy[5] and under the White Paper for European Defence - Readiness 2030[6].

First large-scale industrialisation efforts are now underway all over the world, particularly in the USA, driven by massive private investments from high-tech companies, and in China, powered largely by public funding.

Europe has achieved remarkable advances in quantum scientific excellence: it boasts the world's largest concentration of quantum talent and ranks first globally in the number of scientific publications. The EU also has one of the largest quantum startup ecosystems[7]. Approximately one third of all quantum companies worldwide are based in the EU[8], and EU vendors supply nearly half of the hardware and software components used in quantum computers[9].

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[1] Quantum technologies leverage the principles of quantum mechanics to perform tasks that are either impossible to solve or highly inefficient for traditional technologies. The main areas of quantum technologies include quantum computing and simulation, quantum sensing and quantum communication.

[2] The Draghi report on EU competitiveness

[3] For the purposes of this Strategy, **dual-use potential** denotes the capacity of quantum technologies to serve both civilian and security/defence ends. It is employed here in a broader, forward-looking sense than the legal term 'dual-use items' under Regulation (EU) 2021/821 on export controls.

[4] Commission Recommendation (EU) 2023/2113 of 3 October 2023 on critical technology areas for the EU's economic security for further risk assessment with Member States

[5] JOIN(2023) 20 final; https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023JC0020

[6] White Paper for European Defence – Readiness 2030 | EEAS

[7] McKinsey & Company, Quantum Technology Monitor – April 2024

[8] Lewis, A., Scudo, P., Cerutti, I., Travagnin, M., Marcantonini, C. et al., Future Directions for Quantum Technology in Europe, Publications Office of the European Union, Luxembourg, 2025, JRC141050. Forthcoming mid July

[9] European Investment Bank – A Quantum Leap in Finance (2022)

However, Europe is currently **lagging behind in translating its innovation capabilities and future potential into real market opportunities**. As a result, it now ranks only third globally in patents filed for quantum computing, sensing, and communication[10].

Moreover, **Europe's efforts remain fragmented across Member States**, national and regional funding agencies. Over the past five years, the EU and the Member States have invested more than EUR 11 billion in quantum technologies. While several Member States have developed their own national strategies and roadmaps, insufficient coordination has led to duplication of efforts, inefficient use of resources, and growing competition for talent. This risks undermining the EU's ability to build critical mass and scale, slowing down the commercialisation pipeline, ultimately limiting the development of a globally competitive European industrial capacity and a unified European quantum market.

In addition, **while Europe plays a leading role in early-stage quantum entrepreneurship, its emerging ecosystem is currently lacking sustainable financial support and sufficient market perspectives.** Europe also lacks early adopters of quantum technology among big industrial players, depriving emerging startup ecosystems of sufficient market perspectives.

Building on the Competitiveness Compass[11], which includes "quantum" amongst the key tech sectors that will matter in tomorrow's economy[12], this initiative presents, in strong alignment with quantum stakeholders[13], a comprehensive strategy to secure a leading position for Europe in the global quantum race. In supporting the development of this technology with dual-use potential in the EU, this strategy will also help implement the recommendations of the Preparedness Union Strategy[14] and the Niinistö report[15] and the White Paper for Defence – Readiness 2030[16], the Internal Security Strategy ProtectEU[17] as well as the International Digital Strategy for the EU[18].

1.2 Quantum Europe: The Vision and the Strategic Implementation Framework

Europe is very well positioned to be a leader in the ongoing quantum revolution. The vision is to transform Europe into a quantum industrial powerhouse and a global market leader in quantum technologies, building on sustained scientific leadership.

The EU's strategic vision capitalises on its existing strengths: world-class research, scientific excellence, a vibrant startup base, and a strong public investment structure. These key pillars are essential to address fragmentation, accelerate industrial deployment and ensure strategic autonomy in quantum technologies.

To achieve this vision, the Strategy focuses on five interconnected areas:

[10] See footnote 8.
[11] Competitiveness compass - European Commission
[12] The European Economic Security Strategy and its Commission Recommendation of 3 October 2023 includes quantum amongst the critical technology areas
[13] As expressed in the replies to the Call for Evidence launched ahead of the publication of the Quantum Europe Strategy: Quantum Strategy of the EU. Stakeholders expressed the view that the Quantum Europe Strategy should accelerate the transition from lab to fab without neglecting the capital role of fundamental research, expand the existing pan-European quantum infrastructures, and develop a workforce skilled and educated in quantum. They also highlight the importance of ramping up the Union's manufacturing capabilities and addressing the financial, regulatory and administrative obstacles that limit or slow down startups from scaling up into mature, profitable companies in the Single Market.
[14] Preparedness - European Commission
[15] The Niinisto Report https://commission.europa.eu/document/download/5bb2881f-9e29-42f2-8b77-8739b19d047c_en?filename=2024_Niinisto-report_Book_VF.pdf
[16] See footnote 6.
[17] Commission presents ProtectEU Internal Security Strategy - European Commission
[18] Joint Communication on an International Digital Strategy for the EU, 5 June 2025

- **Area 1 Research and Innovation**: Consolidating excellence across Europe to lead in quantum science and its industrial transformation.
- **Area 2 Quantum Infrastructures**: Developing sustainable, scalable, coordinated infrastructure hubs to support production, design, and application development.
- **Area 3 Strengthening the EU Quantum Ecosystem:** Securing supply chains and the industrialisation of quantum technologies through investments in startups and scaleups.
- **Area 4 Space and Dual-Use Potential Quantum Technologies (Security and Defence)**: Integrating secure, sovereign quantum capabilities into Europe's space, security and defence strategies.
- **Area 5 Quantum Skills**: Building a diverse, world-class workforce through coordinated agile education and training systems and programmes and promoting talent mobility across the EU.

The five strategic areas are supported by a smart implementation approach. As described below, in section 3.1 "The Main Implementation Components of the Quantum Europe Strategy", the approach will build on an iterative life-cycle technology development loop that will continuously link scientific quantum discoveries to real-world applications and to the market, resulting in short and long-term economic impact. This implementation approach will help attract lead industrial and public users, ensuring market access and sustainability of the nascent EU quantum ecosystem.

Figure 1*: Five strategic areas for Quantum Europe*

Complementing the implementation life cycle, the EU will establish a strategic governance framework to oversee and facilitate progress.

The Strategy builds on the 2023 European Declaration on Quantum Technologies[19], which marked a key political step, aligning Member States around shared priorities and European values. It also builds on the findings of the expert working groups from all EU Member States[20], set up under the coordination of the Quantum Technology Coordination Group[21].

2 Quantum Europe Strategic Areas

2.1 Area 1: Quantum Europe Research and Innovation

Europe's quantum research base, supported by several EU and national programmes, has laid a solid scientific foundation. Over the past five years, the EU has invested nearly EUR 2 billion

[19] https://digital-strategy.ec.europa.eu/en/library/european-declaration-quantum-technologies
[20] https://digital-strategy.ec.europa.eu/en/library/shaping-european-strategy-quantum-technology-main-orientations-and-recommendations
[21] https://ec.europa.eu/transparency/expert-groups-register/screen/expert-groups/consult?lang=en&groupID=3931

in quantum technologies, complemented by more than EUR 9 billion in additional public funding from Member States. These funds have supported quantum research and education, the creation of national quantum clusters and hybrid quantum-classical supercomputer centres, the quantum technology industry, and international partnerships.

Despite significant national and EU funding, Europe's quantum research remains fragmented across Member States and instruments, resulting in duplication, gaps in priority areas and competition for scarce talents. Without coordination and a clear focus on shared strategic priorities, Europe will fall short of its quantum ambitions.

The Commission therefore proposes a dedicated **Quantum Europe Research and Innovation Initiative**. It will aim to align the EU's and the Member States' efforts around a commonly agreed Research, Technology and Innovation agenda. It will pool the efforts around common themes and set shared targets to ensure coherence, avoid overlap and build critical mass.

This Initiative will be structured around the following key stages of activity:

- ***Discover:*** Supporting foundational research, technological development and innovation actions in quantum computing, communication and sensing.
- ***From the lab to the fab****:* further investing in building state-of-the-art quantum computing, communication and sensing infrastructures, quantum hardware and relevant enabling technologies, as well as in cutting edge pilot lines and design tools to support industrialisation and ecosystem development.
- ***Apply and use:*** supporting the development of applications in key public and industrial sectors, ensuring the translation of scientific advances across all quantum domains into real-world applications and impact.

In addition to the above, the Initiative will also include investments in talent attraction and skills' development to ensure a well-trained future quantum industrial workforce.

The Quantum Europe Research and Innovation Initiative will be implemented through an EU-level governance framework, which will be defined in the forthcoming proposal for a Quantum Act. In the meantime, the mandate of the EuroHPC Joint Undertaking (JU)[22] will be extended via an amendment to its founding regulation, ensuring seamless coordination with Horizon Europe, Digital Europe, Space and Defence programmes and other funding instruments.

- Amend the EuroHPC JU Regulation to extend its remit to all quantum technologies and, as a first step, transfer present Horizon Europe Pillar 2 R&I quantum activities into the JU [Q3 2025]
- Present the Quantum Act proposal [2026]

2.2 Area 2: Quantum Europe Infrastructures

The EU is investing today in major quantum infrastructure initiatives, such as quantum computing systems under the EuroHPC JU, the EuroQCI[23] secure quantum communication infrastructure under the Union's Secure Connectivity Programme IRIS² [24], as well as in advanced sensing platforms. The EU is also investing in several pilot lines under the Chips JU[25] for preparing the industrialisation of quantum technologies in Europe.

These publicly funded quantum infrastructures are a strategic enabler of Europe's quantum ambition. They provide access to state-of-the-art quantum systems and platforms that would otherwise remain out of reach for most European quantum stakeholders and users due to high

[22] The COUNCIL REGULATION (EU) 2021/1173 establishing the Euro HPCJoint Undertaking.
[23] The European Quantum Communication Infrastructure (EuroQCI) Initiative | Shaping Europe's digital future.
[24] IRIS² | Secure Connectivity - European Commission, Regulation (EU) 2023/588.
[25] Council Regulation (EU) 2023/1782 establishing the Chips Joint Undertaking.

development and access costs, technical complexity or the need for specific services, such as secure communication. They offer a testbed for innovation, a training ground for talent, and a space for industry, SMEs, and researchers to experiment with, understand, and shape the development of new quantum technologies. They are essential to accelerate quantum technology uptake, build industrial capacity, and ensure that quantum benefits are widely distributed across the Union.

Looking ahead, the EU will maintain and expand its investments in public quantum infrastructures across **computing and simulation**, **communications**, and **sensing** as explained below.

2.2.1 Quantum Computing and Simulation

Quantum computing has the potential to revolutionise our ability to solve complex computing optimisation problems far beyond the reach of even the most powerful high-performance computing (HPC) systems. Its impact is expected to be catalytic across numerous areas e.g., in pharmaceutical and chemical simulation, it could enable the discovery of new drugs and chemicals; in energy, quantum computing may help discover new battery materials or high-temperature superconductors; it also holds significant promise for improvements in areas such as logistics and finance. In addition, quantum computers can solve such problems in a much more energy-efficient way than classical supercomputers. Rather than replacing HPC systems, quantum computers will complement them, acting as accelerators to boost the overall performance of the computing solution, delivering results much faster and in a much more energy efficient way. Quantum is also increasingly used alongside and in support of AI. For example, quantum can accelerate the training of AI models, while AI contributes to quantum error correction, boosting overall system reliability.

Quantum computing is currently at a defining stage: while small-scale quantum processors exist, the main global challenge is to scale up to fully operational quantum computers that can definitely demonstrate the quantum computing advantage. The key challenge now is to build larger-scale machines that can deliver a clear quantum advantage[26] over classical computers. In the next 5–10 years, the ability of quantum computers to solve real-world problems will grow enormously. That is why the EU and its Member States, as well as other major players – from Australia, Canada, China, Japan, South Korea, United Kingdom, to the USA, are heavily investing in quantum technologies racing for leadership in the quantum revolution[27]. Multiple quantum computing platforms are under development today, each based on a different technological approach[28]. Table 1 lists the quantum computers provided by companies headquartered in different regions of the world.

[26] OECD (2025), "A Quantum Technologies Policy Primer". *Quantum advantage* refers to the point at which a quantum computer performs a specific task more efficiently, faster, with higher accuracy, or with less energy than the best possible classical supercomputers. This milestone signals a practical demonstration of the superiority of quantum computing for certain computational problems, even if only within narrow domains.

[27] E.g. U.S. National Quantum Initiative (https://www.quantum.gov/); China's 2030-quantum roadmap; Japan Quantum Technology and Innovation Strategy (https://www8.cao.go.jp/cstp/english/strategy_r08.pdf); Australia National Quantum Strategy (https://www.industry.gov.au/sites/default/files/2023-05/national-quantum-strategy.pdf); Canada National Quantum Strategy (https://ised-isde.canada.ca/site/national-quantum-strategy/en/canadas-national-quantum-strategy); UK National Quantum Strategy https://www.gov.uk/government/publications/national-quantum-strategy.

[28] Representative examples of computing platforms are based on superconducting circuits, trapped ions, neutral atoms, photonics, diamonds or spin qubits. Each of them presents distinct advantages and engineering challenges in terms of computing scalability, fidelity, and coherence.

Technology platform	Superconducting	Ion traps	Cold atoms	Photonics	Spin qubits
EU machines	**17**	6	**8**	5	3
UK machines	4	**6**	0	**5**	2
USA machines	26	7	4	2	0
Canada machines	13	0	0	1	0
China machines	2	0	0	0	0
ROW[29] machines	1	0	0	1	**3**

Table 1: *Quantum Computing and Simulation Suppliers Landscape*

Europe, through national programmes and the EU Quantum Technologies Flagship[30] is developing all major quantum computing technologies as illustrated above. These efforts have led to working prototypes, software toolkits, and several deep-tech spin-offs. Also, through the EuroHPC JU, Europe is already deploying its first prototypes of quantum computing systems in several Member States (see Figure 2). This early deployment serves two key purposes: it supports the emergence of an autonomous, sovereign, and competitive European quantum industry by creating an early market for hardware and software suppliers, while also enabling the development of the internal market by increasing the number and scale of use cases and users.

Europe has also successfully enabled the early hybridisation of quantum computers with HPC, thus achieving the EU Digital Decade target of having a first quantum-accelerated computer in 2025[31]. This marks a strategic milestone: it supports European quantum hardware ecosystem, fosters the emergence of industrial use cases, and lays the groundwork for more advanced hybrid systems – all of this contributes to the long-term goal of achieving a full-stack quantum computing capability by 2030. This hybridisation will also enable the use of quantum computers by European AI Factories[32], thereby contributing to achieving the objectives of the AI Continent Action Plan[33].

Looking ahead, the Quantum Europe Research and Innovation initiative will further support coordinated activities to accelerate the transition from today's first-generation quantum devices to fully operational machines. The goal is to position Europe to acquire next-generation quantum computers primarily from EU providers, while progressively scaling these platforms to reach approximately 100 error-corrected qubits[34] per system by 2030 – a target aligned with industry roadmaps for achieving meaningful computational advantage. **By 2035, Europe aims to become the first continent to reach a scale of thousands of error-corrected qubits per platform, a threshold considered necessary to solve real-world problems.**

Achieving this milestone would represent a turning point in practical quantum advantage[35] and position Europe as a global leader in quantum computing. It will reinforce the development of

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[29] Rest Of the World.
[30] Homepage of Quantum Flagship | Quantum Flagship
[31] Hybrid quantum/HPC platforms are integrating quantum processors with classical HPC systems to enable early co-processing, with the quantum processors acting as computing accelerators of the traditional supercomputers. Three hybrid platforms, in France, Germany and Finland, are now operational within EuroHPC and national infrastructures. By the end of 2025, hybridisation will be standard across all European quantum computing facilities, solidifying a significant accomplishment.
[32] AI Factories | Shaping Europe's digital future
[33] AI continent - European Commission
[34] Today's quantum computers are delivering results that are not yet fully accurate (quantum calculations are still prone to significant errors). Implementing effective fault correction, which will result in error-corrected qubits (i.e. the processing units of a quantum computer) providing accurate computing results, is therefore an important milestone for any future fully-operational quantum computer.
[35] See footnote 26.

Europe's quantum computing companies and will help foster the development and implementation of lead user applications while strengthening the Union's technological autonomy.

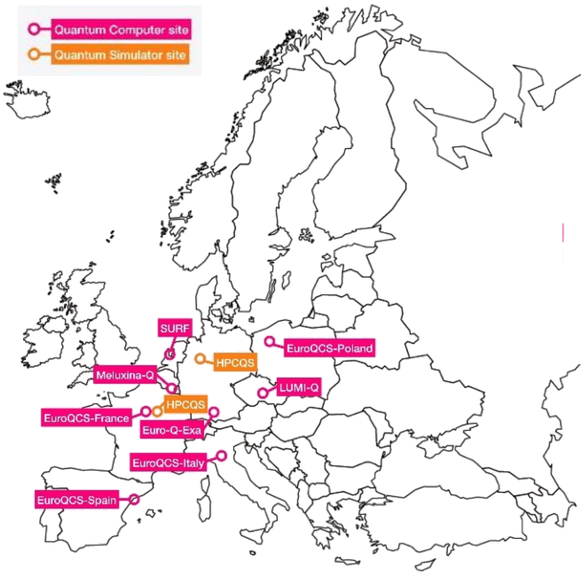

Figure 2*: Map of EuroHPC supercomputers, quantum computers and simulators*

At the same time, **Europe will continue investing in quantum simulators**[36], which can mimic the behaviour of a quantum system while using less complex hardware. These quantum simulators are already enabling breakthroughs in materials science, quantum chemistry, and fundamental physics. Europe is at the forefront of developing and deploying these platforms, which are expected to deliver valuable results earlier than universal quantum computers due to lower hardware requirements.

An EU ***Quantum Computing and Simulation Roadmap*** will be developed, establishing clear benchmarks and a monitoring process to track the technological progress and maturity of the different types of quantum platforms. The roadmap will allow to regularly assess which of them are most advanced or hold the greatest long-term promise. This evidence-based approach will guide Europe's strategic decisions and help prioritise future public investments in quantum computing.

- Publish the EU Quantum Computing and Simulation Roadmap [2026]
- Expand the number and capacity of EuroHPC-based quantum computing systems [2026 onwards] and set up a monitoring framework for quantum computing [2026]

2.2.2 Quantum Communications

Quantum communication enables ultra-secure data transmission, protects critical infrastructures, and safeguards sensitive information against future quantum-enabled cyber threats[37]. It also enables to establish quantum communication networks necessary for interconnecting quantum devices such as sensors and computers, into a so-called '**Quantum Internet**'. Thanks to its dual-use potential, it is supporting both civilian applications (e.g.,

[36] PASQuanS2: Programmable Atomic Large-scale Quantum Simulation 2 - SGA1 | PASQuanS2.1 | Projekt | Fact Sheet | HORIZON | CORDIS ! European Commission

[37] The threat posed by quantum computer to current cryptographic protocols.

protecting financial transactions, securing public networks) and defence needs (e.g., secure communications for military and national security operations). Through initiatives like the **EuroQCI**[38] and the **Quantum Internet**, the EU is building fully autonomous and trusted quantum communication infrastructures, which will protect critical data flows, secure public communications and critical infrastructures, and strengthen Europe's internal security in line with the ProtectEU strategy[39].

The EuroQCI Initiative

The EuroQCI initiative develops a secure quantum communication infrastructure spanning the whole EU, including its overseas territories. It is part of the Union's IRIS² initiative and will be composed of a terrestrial segment relying on fibre communications networks linking strategic sites at national and cross-border level, and a space segment based on satellites.

The initiative is progressing rapidly, with 26 Member States currently deploying national terrestrial quantum communication networks, and which will also be used to test a secure communication Quantum Key Distribution (QKD) satellite (Eagle 1), scheduled for launch in 2026 and which will be the first European in-orbit demonstrator.

These terrestrial quantum communication networks are being used to implement and test QKD in real-world environments. Pilot projects include secure hospital-to-hospital transmission of medical data, encrypted communication between government institutions and QKD links for critical infrastructure like power grid control centres. They are demonstrating how QKD can safeguard essential public services and national operations.

To support this deployment, the EU is leveraging a fully European supply chain of quantum components, devices and systems[40]. A comprehensive QKD testing and evaluation facility is also being deployed, offering pre-certification environments for QKD components and preparing for their integration into end-to-end systems, and network architectures[41].

Moreover, this activity is closely related to EU cybersecurity policies, such as the NIS2 Directive, the upcoming review of the Cybersecurity Act and ENISA's Quantum-Safe Cryptography roadmap to ensure that quantum communication, sensing and computing infrastructures adopt defence-grade security measures, supply-chain integrity checks and incident-response capabilities from the outset.

Other leading regions are also investing in terrestrial and space quantum secure capabilities. China, for example, has demonstrated space-to-ground QKD and developed over 2 000 km of intercity secure terrestrial links[42]. The USA, on its side, is investing heavily in quantum internet testbeds and national lab partnerships, but has not yet launched a federated, secure communication programme at a continental scale. The European model, integrating terrestrial and satellite segments via IRIS², and building on secure-by-design principles and EU-controlled components, positions the EU at the forefront of trusted quantum networks development.

In the period 2025-2035, the EU will further expand the EuroQCI initiative.

First, in the period 2025-2030, the EU will **deploy cross-border terrestrial quantum links connecting Member States**, as well as ground stations linking the EuroQCI terrestrial

[38] The European Quantum Communication Infrastructure (EuroQCI) Initiative | Shaping Europe's digital future

[39] Commission presents ProtectEU Internal Security Strategy - European Commission

[40] "These technologies include quantum random-number generators (QRNG), quantum single-photon sources and detectors, entanglement-based QKD modules and integrated telecom-grade platforms. The supply chain is certified under the EU Secure Connectivity Programme (Regulation (EU) 2023/588)."

[41] This facility enables rigorous characterisation, security testing, and early support for standardisation, closely aligned with the activities of ETSI - Quantum Key Distribution www.etsi.org/technologies/quantum-key-distribution

[42] Through its Beijing-Shanghai backbone and Micius satellite programme, now succeeded by Jinan-1.

segments with the EuroQCI satellites for space-based quantum key distribution. By 2030, a first fully EU-interconnected experimental terrestrial and space secure communication network will thus be created.

Second, **the EU will facilitate market uptake and security certification**. It will continue supporting the further development, maturation and deployment of quantum communication technologies and protocols[43] and their regular integration in EuroQCI. The EuroQCI space segment will also be upgraded to deliver end-to-end space and terrestrial secure QKD services, which will be gradually integrated in the next generation of IRIS² space services. The overall EuroQCI infrastructure will be certified under a harmonised EU scheme to ensure trust and compliance.

The Quantum Internet Initiative

The Quantum Internet initiative complements EuroQCI by preparing the future generation of quantum networks. It lays the foundation for distributed quantum computing and sensing, and ultra-secure data sharing.

Europe has already defined a complete architecture specification for a quantum Internet network and has demonstrated quantum networking at the metropolitan scale[44]. Use case frameworks have been initiated, and ecosystem-building is underway with the launch of the Quantum Internet Alliance (QIA)[45] Technology Forum, the first global open forum dedicated to the quantum Internet. Europe has also already seen its first industrial quantum Internet spin-offs and product launches, signalling the early technology transfer to industry in this field.

The Quantum Europe Research and Innovation Initiative will support the further technological evolution of the Quantum Internet[46] and ensure interoperability between different underlying computing platforms. In 2026, it will support the launch of a pilot facility for the European Quantum Internet, enabling testing of key quantum-safe components and early use cases, secure quantum-cloud services, distributed computing and advanced validation environments bridging research and deployment ahead of full operation. The objective is to **deploy a fully operational quantum safe communication network by 2030 as a first step towards a federated Quantum Internet**. This will also help position the EU at the forefront of international standardisation in this area. In parallel, as the advancement of quantum computing poses risks to the security of our communications[47], the EU and its Member States are now implementing **the post-quantum cryptography Recommendation**[48] and have just published a **Roadmap**[49] for the transition to post-quantum cryptography.

[43] Examples of such technologies include next-generation long-lifetime, high-fidelity optical memories critical for quantum repeater operation, and building and demonstrating fully operational quantum repeaters linking metropolitan networks, tested both in lab and real-world conditions.

[44] The initiative has been successfully delivered *entanglement* between two independently operated quantum network nodes, separated by 10 km of optical fibre. Equally, there have been technological advancements with quantum Internet hardware development including quantum repeater technologies and quantum repeater nodes, as well as advancements in quantum software stacks. https://quantuminternetalliance.org/

[45] https://quantuminternetalliance.org/

[46] Examples: quantum memory scalability, robust entanglement distribution, and quantum network software stack development.

[47] For example in a concept known as 'store now, decrypt later', criminal actors already accumulate encrypted information, such as stolen databases, protected files, or communications data; and hold onto them with a view to later decrypt them with quantum computers for malicious purposes. See for example: The Second Quantum Revolution: the impact of quantum computing and quantum technologies on law enforcement (Europol report 2024).

[48] Recommendation on a Coordinated Implementation Roadmap for the transition to Post-Quantum Cryptography | Shaping Europe's digital future

[49] This roadmap specifies the quantum-safe algorithms, development standards and certification schemes to develop in order to protect sensitive information and critical infrastructures. EU reinforces its cybersecurity with post-quantum cryptography | Shaping Europe's digital future

- Deploy the first EU-interconnected experimental quantum terrestrial and space secure communication network [by 2030]
- Publish a Quantum Communication Roadmap [2026]
- Launch a pilot facility for the European Quantum Internet [2026]

2.2.3 Quantum Sensing

Quantum sensing leverages quantum properties to measure physical features with unprecedented sensitivity and precision, significantly surpassing classical sensor capabilities[50]. It has an enormous potential across many diverse fields, from healthcare, climate change or groundwater resource monitoring to security, defence and space or navigation.

The EU Quantum Flagship has played a leading role in advancing quantum sensing technologies from basic science to application-driven research. Functional prototypes are already being tested in real-world environments, showcasing Europe's leadership in both sensor innovation and in preparing the ground for industrial deployment and adoption in applications with dual-use potential.

Quantum gravimeters

The EU is now developing a ***network of mobile and stationary quantum gravimeters***[51], which allow for the detection of subsurface features located up to several tens of kilometres underground, including water reservoirs, gas deposits, mineral resources, magma chambers, or buried infrastructure. They are particularly valuable for monitoring underground changes over time, supporting applications in earth science and geophysics (including subsurface mapping and earthquake early warning), climate science (e.g. tracking glacier loss and groundwater depletion), natural hazard prevention, civil engineering, and strategic applications in defence and civil protection, such as the detection of underground man-made structures and the monitoring of critical infrastructure.

Under the Quantum Flagship, in the next 3-5 years, a network of ground-based gravimeters will be deployed across Europe, complemented by gravimeters embarked on high-altitude platforms. In parallel, the EU is planning to launch a first quantum space **gravimetry Pathfinder Flight**[52] after 2030. The integration of quantum gravimetry under IRIS^2 follow-up missions will equally be explored. These efforts could pave the way for a full-scale network of ground, airborne and space-based gravimeters for Earth observation purposes, supporting both scientific research and strategic applications, including those with dual-use potential.

Quantum Magnetic Resonance Imaging (Q-MRI)

In medical diagnostics, EU research has paved the way for quantum-enhanced imaging, using quantum sensors to measure magnetic signals at molecular level. These systems hold enormous promise for precision medicine and personalised healthcare by accelerating the detection of cancer and neurodegenerative diseases, and by modernising Europe’s diagnostic infrastructure.

In 2025, under the Quantum Flagship, the EU will support the setting-up of the European **Q-MRI Pilot Infrastructure[53]** across a number of Member States. This infrastructure will enable

[50] E.g. quantum sensing advantages over traditional sensing techniques include: higher detection sensitivity of physical quantities such as magnetic fields, temperature, gravity, etc.; improved accuracy and precision of measurements, better resolution.
[51] Taking atom interferometric quantum sensors from the laboratory to real-world applications, Nature Reviews Physics, 1, 731–739. https://doi.org/10.1038/s42254-019-0117-4
[52] https://carioqa-quantumpathfinder.eu/: led by CNES, DLR, and Airbus.
[53] Quantum-enhanced and AI-powered metabolic MRI Diagnostics

clinical validation of quantum-enhanced MRI systems[54], and provide open access for accredited research centres, hospitals and industry partners to test approved quantum-imaging prototypes. By integrating AI-based analysis tools, the infrastructure will boost diagnostic accuracy, support earlier intervention and help lower overall healthcare costs. Over time, this network will be progressively scaled up across additional Member States.

The Quantum Europe Research and Innovation Initiative will also continue financing the further R&D development of Q-MRI sensors and their integration into public health research infrastructures, paving the way for their further industrialisation.

In addition to the above, the EU will continue supporting research in ***higher sensitivity and new imaging contrasts*** that will open novel diagnostic capabilities, for example in neurology (e.g., early-stage Alzheimer's brain connectivity disorders) or oncology (e.g., cancer detection through metabolic imaging).

To further advance its strategic positioning and planning in quantum sensing technologies and metrology and testing infrastructures, **the EU will develop a coordinated European Quantum Sensing, Measurement and Testing Roadmap** and support relevant standardisation efforts in collaboration with metrology institutes and the Member States. A major aim will also be to ensure European strategic autonomy through secure and compliant supply chains for critical sensing components and systems.

- Deploy a distributed system of gravimeters across Europe [2026 onwards]
- Publish a Quantum Sensing Roadmap [2026]
- Establish a European Q-MRI Pilot Infrastructure and scale it up across Europe [2025 onwards]

2.3 Area 3: The Quantum Europe Ecosystem

A vibrant, interconnected and robust quantum ecosystem is critical to Europe's long-term capacity to develop and deploy quantum technologies at scale. Today, the European quantum ecosystem encompasses around 70 startups and scaleups, deep-tech investors, research and innovation organisations, national competence clusters, and industrial supply chains. **However, this ecosystem remains very fragile**. It is dominated by **small startups and scaleups that face significant barriers to growth: unstable revenue streams, limited access to scaleup capital,** and **limited industrial demand** in the near term. Moreover, the EU lacks large-scale quantum hardware providers and anchor end-users capable of catalysing demand and accelerating industrial adoption. This structural weakness limits both private investment and the emergence of critical supply chains.

Without coordinated intervention and accessible pathways to real market opportunities, many of these startups risk disappearing or relocating to more supportive ecosystems outside Europe.

To support this ecosystem, Europe must take decisive steps to foster industrialisation, scale promising actors, ensure strategic supply chains, develop lead markets, protect strategic assets, and train the next generation of quantum professionals.

2.3.1 From the lab to the fab and to industrialisation

The global market for quantum technologies is still emerging. From today's EUR 2-3 billion, it is forecasted to reach EUR 155 billion by 2040[55]. This prospective growth implies the need for a coordinated, unified EU industrialisation strategy enabling European companies to take advantage of this upcoming opportunity.

[54] They will be deployed as controlled clinical trials under the EU Medical Devices Regulation.
[55] McKinsey Quantum Technology Monitor 2024.

Quantum chips are the key underlying enabler of quantum industrialisation and market development. Today, however, their evolution is at a stage comparable to that of semiconductors 30-40 years ago, with most current quantum devices being mainly proprietary designs and, to a large extent, handmade.

Europe must move swiftly towards the **first large-scale, low-cost quantum chips manufacturing, using, as much as possible, processes compatible with** those for **microelectronics and photonics or developing new processes where necessary**. This approach would allow to leverage existing semiconductor infrastructure, reduce costs and accelerate time-to-market for quantum chips and devices.

Moving in this direction, the EU **will soon be launching its first six quantum pilot lines through the Chips Joint Undertaking** in line with the Chips Act[56]. With a joint EU and Member State funding of EUR 40 to 50 million per pilot line, they will support early prototyping, design validation, and process development, while encouraging practical use cases by closely engaging with industry. These six pilot lines will expand the groundwork laid by the Quantum Flagship's experimental pilot lines[57] into industrial pilot lines.

In the next 3-5 years, these efforts will enable Europe to mature further and consolidate quantum and other enabling technologies and processes, before building the first quantum foundries, towards 2030. To support full industrialisation planning and its implementation, and in line with the EU Competitiveness Compass, **the Commission will release a full-scale Quantum Chips Industrialisation Roadmap within 2026**.

As design facilities and libraries are fundamental for any quantum chips ecosystem, the EU will launch **a quantum design facility** under the Chips Joint Undertaking. The facility will run alongside the cloud-based design platform of the semiconductor industry and will be connected with the quantum pilot lines.

Technical interoperability and new standards will also be needed to facilitate quantum industrialisation. In 2026, the EU will therefore publish **a European Quantum Standards Roadmap** and, together with Member States, will support an active participation of industry stakeholders in European and international standardisation bodies.

2.3.2 Strengthening and scaling up the emerging European quantum ecosystem

For the European quantum ecosystem to truly scale up, the following measures will be put in place.

First, **setting up** a **Europe-wide, centralised network of open-access quantum testbeds**. Quantum technologies rely on highly sensitive systems and laboratories[58] that are technically complex and extremely costly. This makes it impractical for most actors, especially SMEs and startups, to build or maintain such facilities independently. To expand access to testing facilities, dedicated equipment, and experimentation possibilities, the existing pilot facilities of the Quantum Flagship are being transformed into a Europe-wide, centralised network of open-access quantum testbeds. These facilities will provide developers, startups, SMEs and researchers with services and access for testing, validating and benchmarking their quantum devices[59]. This will accelerate the transition from prototype to market and support certification efforts, which are essential for the emergence of reliable supply chains and customer confidence across sectors.

[56] (EU) 2023/1781: European Chips Act | Shaping EuroUnclearpe's digital future
[57] QU-PILOT and QU-TEST.
[58] These include, among others, ultra-clean environments, cryogenic cooling, vacuum systems, and precision control electronics, etc.
[59] In line with the upcoming European Strategy on Research and Technology Infrastructures.

Second, **expanding Quantum Competence Clusters (QCCs).** These clusters are already embedded in national and regional innovation ecosystems across several Members States. They are regional hubs providing shared infrastructure and services, while connecting research and industry players. The Quantum Europe Research and Innovation Initiative will support expanding and networking these clusters to cover the whole of the EU, also in Member States which do not yet have such clusters. QCCs will be acting as distributed centres of expertise, serving as the quantum ecosystem's connecting tissue – linking startups, researchers, and industrial partners with infrastructures, pilot lines, and design facilities across the Union. They will foster collaboration[60] and coherence across all quantum strategic areas – from research to industrialisation, as well as skills development. Just as the European Digital Innovation Hubs (EDIHs), QCCs will offer services tailored to regional strengths but embedded in and boosting pan-European cooperation.

Third, **promoting intellectual property (IP) protection mechanisms** so that quantum companies can use them to ensure strategic control over key innovations and prevent the outflow of critical assets.

Fourth, **accelerating the industrial uptake of quantum technologies**. The EU will implement a coordinated approach to foster lead users across both the public and private sectors. In this respect, **public procurement will be a key tool to drive early adoption and create first market opportunities**. The EuroHPC JU is already supporting the purchase of the first quantum computers through public procurement. In addition, the Commission will support innovation-oriented procurement schemes that enable hospitals, infrastructure operators, critical public services, and government agencies to act as launch customers for quantum-enabled solutions. This will be supported by tailored financial incentives and deployment frameworks for public bodies that will be ready to act as first movers. By positioning **Member States as first institutional buyers of European quantum technologies,** a strong signal will be sent to markets and investors, hence supporting ecosystem development and commercial viability.

Fifth, **connecting quantum startups with European corporates**. This will be essential for the market expansion of the startups. The Commission, in cooperation with the quantum ecosystem[61], will launch sector-specific challenges, particularly in aerospace, automotive, energy, manufacturing, logistics and pharmaceuticals, to encourage large industrial players to become strategic co-development partners and lead users.

Finally, a growing quantum ecosystem will require an influx of relevant talent. This is further developed in Section 2.5 below.

2.3.3 Investing in quantum startups and scaleups

While pre-seed and seed-stage funding is widely available from public sources, Europe attracts only 5% of the global private quantum funding, compared to over 50% captured by the USA. This funding gap is particularly pronounced at later stages of development[62], presenting the risk that EU startups could be acquired by non-European investors, with potential losses in IP, critical technologies, technological sovereignty and talent.

Therefore, investment funds, including publicly backed private funds, will be encouraged to crowd in substantial capital investment for the development of quantum technologies. These include support from the European Innovation Council (EIC)[63] Fund, the European Investment

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[60] In accordance with relevant EU antitrust rules such as the 2023 Guidelines on the applicability of Article 101 TFEU to horizontal co-operation agreements, as applicable.
[61] European Quantum Industry Consortium Homepage - QuIC
[62] The Future of European Competitiveness – A Competitiveness Strategy for Europe
[63] Between 2021 and 2024, the EIC has already dedicated around EUR 350 million to foster the growth of quantum technology startups. Additional EIC investments into quantum scaleups of up to EUR 30 million per company are prepared following the EIC STEP Scaleup Call as part of the Strategic Technologies for Europe Platform.

Bank (EIB) Group's European Tech Champions Initiative[64], or through first-loss guarantees and tailored co-investment schemes via InvestEU.

The EU Startup and Scale Up Strategy adopted in May 2025[65] announced setting up the **Scaleup Europe Fund** as part of the EIC fund, to mobilise significant private funds and make direct equity investments in strategic sectors such as quantum. The EU Startup and Scale Up Strategy also offers dedicated solutions aimed at facilitating access to finance, public procurement, markets, services and talents for innovative startups and scaleups.

In addition, as proposed in the mid-term review of Cohesion policy (MTR)[66], managing authorities could use the opportunity, supported with incentives and flexibilities, to reallocate funds towards investments in, among other priorities, Strategic Technologies for Europe Platform (STEP) objectives. The Commission urges Member States and regions, when reprogramming under the MTR, to focus on breakthrough, innovative companies, helping those companies that contribute to Europe's strategic sectors and value chains, such as quantum technologies.

Finally, in the context of the Savings and Investments Union[67], the Commission will put forward measures that will address fragmentation in the single market for financial services and remove obstacles to seamless cross-border investments in the EU, including in venture capital which is instrumental to the development of quantum technologies. The EU will, amongst others, stimulate equity investments by institutional investors; simplify listing rules in the implementation of the Listing act; put forward measures to support exits by investors in private companies; explore with the EIB potential initiatives that aim to crowd-in private investment into venture and growth capital and address barriers to national taxation procedures[68].

2.3.4 Strengthening the Security of the supply chain

A vibrant quantum ecosystem supported by resilient supply chains is essential for strengthening Europe's economic security. While the EU's longstanding openness to trade, investment, and research has been and will remain of key importance for the development of Europe's quantum ecosystem, it also poses certain challenges. On the one hand, European quantum companies and researchers rely on and greatly benefit from continuous flow of supply from trusted sources. On the other hand, these supply chains can be at risk of being weaponised. Therefore, it is essential to identify and address critical vulnerabilities in the European quantum supply chain to mitigate risks arising from EU's excessive dependency on non-European sources. Mapping risks and closely monitoring the evolution of the emerging quantum ecosystem are therefore an essential part of the European approach to building a healthy, secure and competitive European quantum deep-tech landscape.

As part of the European Economic Security Strategy[69] as well as of the Observatory of Critical Technologies[70], and in close cooperation with stakeholders and Member States, **the Commission is conducting an EU-wide Quantum Technology Risk Assessment to map supply-chain vulnerabilities**, looking in particular at materials, components, and key technologies. The aim of these assessments is to identify strategic dependencies, potential bottlenecks, and systemic vulnerabilities in the quantum technology supply chain, spanning

[64] Fund of Funds to Support European Tech Champions.
[65] https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/jobs-and-economy/eu-startup-and-scaleup-strategy_en.
[66] 'A modernised Cohesion policy: The mid-term review', COM(2025) 163
[67] Savings and investments union - European Commission
[68] While respecting relevant State aid rules, as applicable.
[69] JOIN(2023) 20 final; https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023JC0020. This strategy also encompasses risk assessments with regard to technology security and technology leakage, for which quantum technologies is one of four focus areas so far.
[70] https://defence-industry-space.ec.europa.eu/eu-space/eu-observatory-critical-technologies_en

from rare materials to precision components, control electronics, and software stacks. The findings will inform targeted mitigation measures, including diversification of suppliers, enhanced European production capacity, partnering with supplier countries under the Global Gateway, and risk-sharing mechanisms. The first results are expected in 2026. In addition, the role that quantum technologies play in ensuring the security and public order of the EU, is reflected in discussions of ongoing and future initiatives concerning both inbound and outbound investments as well as in the context of export controls.

Building on the above findings, the upcoming **Quantum Act** will further support the strengthening of the quantum ecosystem and, more broadly, the industrialisation efforts above by incentivising Member States and companies, investors and researchers to invest in (pilot) production facilities, supporting these activities under the umbrella of large-scale EU-wide initiatives, or national, or regional efforts.

- Establish six new quantum pilot production lines under the Chips Joint Undertaking to scale technologies from lab to the market [2025]
- Release a Quantum Chips Industrialisation Roadmap [2026]
- Launch a quantum design facility [2026]
- Publish a European Quantum Standards Roadmap [2026]
- Expand the network of quantum competence clusters [2026]
- Carry out and finalise EU-wide assessments of supply chain vulnerabilities [2025-2026]

2.4 Area 4: Space & Dual-use quantum technologies (Security and Defence)

Quantum technologies have dual-use potential. Thus, they are essential for enhancing both Europe’s competitiveness and its strategic autonomy in space, security, and defence. Recent advances in quantum technologies promise major benefits for defence and security, including ultra-secure communications, enhanced battlefield sensing and optimised logistics. However, they may also pose risks if adversaries gain a technological edge. To fully leverage their potential while mitigating these risks, proactive policy and oversight measures as well as close coordination with key partners such as the European Defence Agency will be essential.

Quantum technologies in space

Quantum technologies offer strategically significant opportunities for European space missions. Secure quantum communication technologies are already embedded in key EU space initiatives, including EuroQCI/IRIS² and the quantum space gravimeter pathfinder mission. EU space activities also cover the advancement of quantum inertial navigation systems, including prototypes based on quantum optical sensors under the Galileo programme, for autonomous positioning in environments where global navigation systems (GNSS) have been intentionally disabled or spoofed. These prototypes are expected to be tested on-board Galileo satellites in the coming years to evaluate their potential for operational deployment. In parallel, quantum clocks are also being assessed for future Galileo upgrades. Quantum computing is also expected to enhance space engineering through advanced computational capabilities, including for enhancing human understanding of the universe. A large number of quantum-based space applications have also great potential for military and intelligence purposes.

Together, these quantum technologies promise significant advances in terms of timing stability, precision, and resilience, reinforcing Europe’s strategic autonomy in satellite navigation. In order to further explore the potential of quantum in space, the Commission will extend the current cooperation framework with the European Space Agency (ESA) to jointly develop **a Quantum Technology Roadmap in space** and ensure complementarity and synchronisation of quantum space-related activities.

Quantum technologies for security and defence

The dual-use potential of quantum technologies means that their breakthroughs can also bring significant benefits to strategic security and defence applications. For example, quantum computing could radically transform defence strategies by enabling faster decision-making and helping solve complex operational and logistics challenges. It can also help design new military-grade materials or safeguard sensitive information from cyber threats.

Quantum computing is poised to transform key security and defence applications such as simulations of extreme-temperature fluid flows, combustion dynamics, or heat-resistant materials discovery. Quantum sensing technologies offer critical capabilities for defence, including highly accurate gravimetry, magnetometry, and inertial navigation. These sensors enable detection of underground structures, submarine tracking, and advanced threat detection. At the same time, quantum communications, particularly quantum key distribution, ensure ultra-secure information exchange across terrestrial and satellite networks, protecting military and intelligence data against spying or future quantum-enabled cyber threats. Both sensing and communication technologies are therefore key enablers for Europe's strategic autonomy and operational superiority in defence and security contexts.

Global players such as the USA[71] and China are heavily investing in space and military applications of quantum, including Global Navigation Satellite System (GNSS)-independent navigation, secure satellite and terrestrial communications, quantum lidar[72] and quantum enhanced radars. Quantum technologies have also begun to influence broader alliances and cooperative frameworks[73].

In the EU, several Member States[74] already include investments in their defence programmes for developing defence-ready quantum technologies, such as cold atom sensors, diamond sensors, or quantum computers and are exploring use cases, such as advanced timing, GNSS free positioning, and seabed cartography.

To reinforce investment opportunities in dual-use and critical defence technologies under the EU programmes, the Commission has recently presented a proposal[75] amending the scope of relevant existing instruments. The Commission has also put in place measures to leverage technologies with dual-use potential, including quantum, for defence, for example through actions under the European Defence Fund and its EU Defence Innovation Scheme (EUDIS).

The underlying premise of all these activities is for Europe to ensure that quantum developments remain accessible, secure, and are free from third country export regulations, while aligning with European defence and security goals.

The EU and NATO also recognise quantum technologies as mission-critical enablers for intelligence, surveillance, navigation, and secure infrastructure. In 2024, NATO launched the Transatlantic Quantum Community with an ambition to become "a quantum-ready alliance". The Commission and NATO engage on quantum technologies as part of the EU-NATO Structured Dialogue on Emerging and Disruptive Technologies (EDTs).

The **European Internal Security ProtectEU strategy**, as well as the European Defence Fund, identify quantum technologies as a key area for ensuring the EU's long-term security and

[71] Quantum Benchmarking Initiative: https://www.darpa.mil/research/programs/quantum-benchmarking-initiative

[72] A quantum LiDAR is a light detection and ranging system that uses quantum properties like entanglement to enhance sensitivity and accuracy in target detection and range estimation beyond classical limits.

[73] E.g. BRICS And Quantum Computing

[74] E.g. France (PROQCIMA programme on quantum sensors for defence - https://quantique.france2030.gouv.fr/acces-aux-marches/programme-proqcima), Germany (quantum communication and sensing under BMBF), Italy (cold atom sensors for GNSS-free navigation), Austria (quantum clocks and inertial sensors), Finland (portable quantum sensing systems for defence use).

[75] COM(2025) 188 of 22.4.2025: Proposal for a Regulation amending Regulations (EU) 2021/694, (EU) 2021/695, (EU) 2021/697, (EU) 2021/1153, (EU) 2023/1525 and 2024/795, as regards incentivising defence-related investments in the EU budget to implement the ReArm Europe Plan.

technological edge. Quantum technologies are also mentioned in the **White Paper for European Defence – Readiness 2030** as having the capacity to disrupt and transform traditional approaches to warfare. The White Paper announces that the Commission will contribute relevant quantum advancements, initiatives and programmes to **the European Armament Technological Roadmap.** This will accelerate the transformation of defence, leveraging investment into dual-use advanced technological capabilities at EU, national and private level.

To steer these efforts, **the Commission will develop a dedicated Quantum Sensing Space and Defence Technology Roadmap by 2026**, aligning priorities across civil, security and defence communities. This will help coordinate investments in next-generation quantum sensors, including for gravimetry, navigation and advanced threat detection.

In parallel, starting in 2026, the EU will launch spin-in initiatives to accelerate the uptake of civil quantum innovations into security and defence applications. These initiatives will connect cutting-edge companies and research groups with defence actors, helping shorten development cycles and reinforcing Europe's technological edge in **capabilities with dual-use potential**.

- Sign a cooperation agreement with ESA for the development of a Quantum Technology Roadmap in space [Q2 2025]
- Develop a quantum sensing space & defence technology roadmap [2026]
- Contribute to the European Armament Technological Roadmap [Q4 2025]
- Launch spin-in initiatives to bring-in civil companies and academia for defence applications [as of 2026, onwards]

2.5 Area 5: Quantum Skills

Europe has developed a strong base of academic quantum talent. The European Union has the highest number of graduates in quantum technology-relevant fields worldwide compared to its population, with over 110,000 graduates[76] annually in physics, ICT, engineering, and related disciplines. According to the Quantum Flagship's Strategic Research and Industry Agenda 2030[77], Europe has over 40 specialised Master programmes in quantum technologies and quantum engineering. However, this is still insufficient to meet the projected demand from EU's startups and industry, which faces major shortages of professionals with relevant applied skills. Shortages are most critical in applied fields[78], including quantum software engineering, system integration, and quantum cybersecurity, slowing the commercialisation path for EU-based startups and scaleups.

Under the Union of Skills[79], the Commission is taking several initiatives to address skills' shortages, including those related to quantum. The Commission will establish, in 2026, a virtual ***European Quantum Skills Academy*** to serve as a single, central contact point, providing visibility into available quantum technology training and opportunities for practical application across all levels of education. Under this initiative, the Commission will foster collaboration with academia, training institutions, the research community, and industry partners to design and deliver educational programmes and standalone training modules through an interdisciplinary approach. The programmes will include common curricula at ISCED levels 7 (Master's or equivalent level) or 8 (doctoral or equivalent level) leading to a degree, which uses the European Credit Transfer and Accumulation System (ECTS). Virtual study fairs and scholarship schemes will promote such programmes.

[76] Global Comparison of STEM Education | SpringerLink
[77] Strategic Research and Industry Agenda 2030 (Quantum Flagship): https://qt.eu/media/pdf/Strategic-Reseach-and-Industry-Agenda-2030.pdf
[78] IQM-State-of-Quantum-2025.pdf, RAND Europe: Quantum's Future Workforce Needs More Than Physicists
[79] COM/2025/90 final

Furthermore, to foster future-oriented skills, the Commission will facilitate the development of innovative joint European study programmes, including in strategic sectors and key technological domains such as quantum, potentially through a European degree/label based on commonly agreed criteria.

The Academy will also support, in line with the objective of attracting and retaining global talent of the Union of Skills, quantum fellowship schemes that will allow highly skilled EU and non-EU PhD candidates as well as young professionals living outside of the EU to work in the EU.

To scale up and disseminate its activities, the Academy will develop communications and awareness-raising practices. These will include, among others, a dedicated landing webpage acting as a **Quantum Talent Portal**, integrated in the Digital Skills and Jobs Platform, 'Teach-the-Teacher' modules for university and secondary education instructors to achieve quantum literacy in early education, and the sharing of best practices towards Member states and eligible third countries.

The communication outreach by the virtual Academy will aim to increase public awareness, as well as improve societal understanding, trust, and informed policy engagement in the field of quantum technologies. Importantly, its communication and public awareness activities will contribute as well to enhancing the diversity and close the significant gender gap still present in Europe's quantum workforce[80].

While the virtual Academy marks a first important step, the long-term vision is to establish multiple, networked academies with geographical spread across the EU, linked to Quantum Competence Clusters as well as Semiconductors Competence Centres to multiply their effectiveness.

Additionally, under the Digital Europe Programme[81], the Commission will support a pilot project for a **Quantum Apprenticeship Programme** to prepare a pipeline of quantum specialists trained on real-world projects and ready to (re)enter the EU labour market, as well as introduce "returnship" schemes for professionals. Moreover, to create further virtuous circles between academia and industry, the Commission will develop from 2026 **European Advanced Digital Skills Competitions**, which will involve young people in the co-creation of quantum-driven solutions to key societal and industrial challenges and foster creative and innovative thinking.

As technology develops quickly, the skillset demands of professional profiles related to quantum develop and change, and thus a continuous monitoring of education and training providers and industry needs and workforce demands would be also essential. Under the Union of Skills, the European Skills Intelligence Observatory will monitor timely developments on skills needs on strategic sectors in Europe.

The European Innovation Council will also launch in 2025 a Pilot Programme for **Researchers-in-Residence in Quantum Technology Startups**. This action will facilitate targeted placements of researchers in line with the specific needs of high-growth companies facilitated by a dedicated platform to connect researchers and innovative startups and scaleups.

Finally, the Commission will launch a **European Quantum Talent Mobility Programme** to boost international labour mobility and skills development between the EU, Member States and partner countries, including fellowships for non-EU PhDs and early career professionals in quantum, while retaining and supporting existing workforce to avoid brain drain. To attract, develop and retain excellent international quantum researchers, the Commission will also be

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[80] There are significant gender imbalances in STEM higher education and careers. See the 2024 She Figures report

[81] https://digital-skills-jobs.europa.eu/en/opportunities/funding/digital-2025-skills-08-quantum-academy-step-sectoral-digital-skills-academies

piloting the Marie Skłodowska-Curie action '**MSCA Choose Europe'** scheme, which will also cover, among others, quantum researchers.

- Establish the European Quantum Skills Academy [2026]
- Launch European Advanced Digital Skills Competitions in quantum [as of 2026, onwards]
- Launch a Pilot Programme for Researchers-in-Residence in Quantum Technology Startups [2025]
- Launch the European Quantum Talent Mobility Programme [2026, onwards]

3 Strategic Implementation Framework for Quantum Europe

3.1 The Main Implementation Components of the Quantum Europe Strategy

The European quantum field exhibits unique characteristics: quantum technologies remain largely emergent, with many of their core components - both hardware and software - still at an early stage of maturity. Developing them further through a traditional, linear path from fundamental science to the market would require 10 to 15 years. To speed up the process, the following **tailored technology lifecycle implementation logic** will be put in place, tightly integrating research, innovation, infrastructure, and early market creation in a continuous loop.

A lifecycle approach is particularly vital in the European ecosystem as there are still major scientific and engineering roadblocks[82] across all quantum domains that must be addressed and converted into tangible technologies. Europe must not only solve these problems, but also rapidly transition the resulting solutions to market-ready applications before global competitors lock in strategic dominance.

To address the scientific and engineering roadblocks, the Quantum Europe Research and Innovation Initiative (outlined in Section 2.1. above) will support:

- **targeted science and technology (S&T) efforts** focusing on resolving current key S&T challenges that limit progress across all quantum domains. These will be addressed mainly through top-down S&T calls complementing the usual bottom-up S&T ones.

- **market- disruptive research and innovation activities and targeted actions for maturing specific quantum and enabling technologies**. The goal is to de-risk quantum innovation and accelerate the transfer of major research discoveries for industrial uptake.

In addition, and to reinforce the above, the following approach will be applied:

A Grand Challenge mechanism

The Quantum Grand Challenges will serve as strategic instruments to address well-defined quantum technology problems of high impact. These Grand Challenges are designed to bring together scientists, industrial users, manufacturers, integrators, and actors from both quantum and enabling technologies, in a coordinated effort similar in ambition and structure to past mission-oriented initiatives.

They will focus on individual startups/scaleups to support them in implementing their breakthrough technology roadmap through a competitive and collaborative development

[82] Examples of such roadblocks include in quantum computing, scalable quantum error correction schemes, quantum interconnects for modular architectures, and cryogenic control electronics; in quantum communication, long-distance quantum repeaters, device-agnostic entanglement distribution, and secure, trusted-node-free networks; and in quantum sensing, miniaturised, deployable gravimeters, high-resolution Q-MRI systems, and inertial sensors for GNSS-independent navigation.

process. A Grand Challenge will bring them together with lead industrial users and researchers to co-develop critical, scalable quantum solutions. The participation of lead industrial users is essential for the startups to meet industrial requirements and validate their technologies in industrial environments. Where appropriate, defence actors, including Ministries of Defence and defence companies, may participate as end-users in specific Grand Challenges.

The startups/scaleups selected for the Grand Challenge will be benefiting from a combined set of instruments (grants, equity, loans or other blended finance instruments). From the outset, both public and private financial actors will be involved to ensure alignment with strategic investment goals and maximise impact.

Between 2025 and 2027, the Commission, together with the European Investment Bank and Member States, will pilot at least two such Grand Challenges. The first will focus on fault-tolerant quantum computing systems capable of solving complex industrial problems; the second will target quantum-based Positioning, Navigation and Timing (PNT) systems for environments where the global satellite navigation systems do not work. Subject to available financing, additional Grand Challenges may follow, for example, in quantum-enhanced medical imaging (Q-MRI) to support early disease diagnostics and personalised medicine.

A technology lifecycle approach

All the above efforts will be underpinned by a **technology lifecycle approach, which integrates the five strategic areas of the Quantum Europe Strategy** into a coordinated and iterative development process enabling continuous iteration between discovery, development, testing, and deployment.

Europe's quantum public infrastructures and pilot lines presented in Section 2.2 above are central to this model. These facilities act as a bridge between research and industrialisation. Building, maintaining and scaling them provides the essential physical and organisational foundations to further strengthen and nurture the whole quantum ecosystem. They can help translate research into practical applications by providing the testbeds, facilities, and networks needed to test, validate and scale research breakthroughs. They also serve as excellent playgrounds for attracting talent and developing practical applications and use cases. Finally, they help quantum startups and SMEs get access to the latest technology platforms and lab facilities, where they can further develop their prototypes and prepare them for industrial deployment. The federated network of quantum competence clusters will further act as a catalyst of this virtuous lifecycle approach, linking together research organisations, startups, scaleups, large industry, and infrastructure providers, thus creating bridges between scientific and industrial actors.

To ensure the lifecycle is both robust and fit for purpose, Key Performance Indicators (KPI), milestone tracking, and benchmarking against existing technologies will be set up.

Finally, this integrated model aligns EU and Member State strategies by focusing investments on shared objectives and creating coordinated feedback loops. It avoids duplication, builds critical mass, and enhances Europe's global influence in shaping the development and deployment of quantum technologies.

4 International Cooperation

In a context of growing geopolitical uncertainty and its direct impacts on global investment and trade landscape, Europe must protect its interests, while maintaining its openness and engaging proactively with trusted partners. This notion is reflected in a range of EU's recent policies, including its International Digital Strategy and its Economic Security Strategy.

Priority partners include like-minded countries, in particular those with whom the EU is already coordinating on technology and trade policy issues within the framework of, for instance, Free

Trade Agreements, Trade and Technology Councils[83] or Digital Partnerships[84]. The Commission envisages expanding this cooperation with initiatives covering joint research programmes, coordinated calls, exchange of expertise, reciprocal access to infrastructures, aligned IP frameworks, and preparation of global quantum standards. It will also join forces on concrete quantum applications in sectoral policies, for example to develop new materials. In this context, the EU has already started implementing joint research and innovation projects in quantum technologies with Japan, the Republic of Korea and Canada.

The EU will also engage with the rapidly growing emerging quantum ecosystems that represent economic opportunities for EU companies, offer a competitive boost to EU's quantum industry at the global level, and provide a way for European quantum companies to diversify partnerships and reduce dependencies. This approach will guide bilateral and multilateral partnerships, based on shared values, mutual trust, and the complementarity of capabilities and markets, while ensuring appropriate levels of protection for the EU's interests in strategic areas.

In addition, the EU will strengthen its presence on quantum in international standardisation *fora*, trade dialogues, and multilateral quantum alliances[85].

In all the above, the Commission will work in close cooperation with the Member States to establish a coherent European Quantum International Cooperation Framework that identifies priority countries and areas for structured collaboration. It will also support joint diplomatic initiatives and the development of common European positions on quantum technologies, ensuring that Europe's voice is amplified in shaping global governance and ethics in quantum innovation.

- Extend and launch new bilateral and multilateral cooperation initiatives with like-minded countries [2025 onwards]
- Work with the Member States on a European Quantum International Cooperation Framework [2025 onwards]

5 Governance

Strong and inclusive governance at EU level is essential to steer, coordinate, and monitor the implementation of the Quantum Europe Strategy, fostering participation from the whole Union, both in terms of the involvement of all Member States, representatives of all types of quantum stakeholders but also ensuring gender balance.

First, a **High-Level Advisory Board,** bringing together leading European quantum scientists and technology experts, will provide independent strategic guidance on the implementation of the Quantum Europe Strategy.

Second, a **structured cooperation framework with the Member States** will help ensure coherent implementation across EU-level and national programmes, coordinate annual lifecycle progress across the five strategic areas, and monitor the evolution of the security and resilience of quantum supply chains and its critical components. A **dedicated expert group** bringing all Member States[86] together is already actively operating and will be closely involved in the future work of the EuroHPC JU Governing Board once the regulation of the JU is amended.

[83] With U.S. and India.
[84] With Canada, Japan, Singapore and South Korea.
[85] At the June 2025 G7 Summit, Leaders acknowledged quantum's transformative potential and pledged to boost investment, foster trusted global cooperation, and strengthen ties between national measurement institutes through a G7 Joint Working Group. See: Kananaskis Common Vision for the Future of Quantum Technologies.
[86] European Quantum Technology Coordination Group of Member States Representatives.

Finally, the Commission will continue its close interactions with the whole European quantum community including academia, startups, industrial actors, and innovation stakeholders and their representatives.

6 Conclusions

Quantum technologies are at a turning point. The EU has established itself as a world leader in quantum research and laid the foundation for a competitive industrial base. However, the global race to harness quantum technologies is accelerating. Leading nations are scaling up public investment, coordinating national strategies, and consolidating research-to-industry pipelines to achieve technological sovereignty and economic advantage. The dual-use potential of quantum technologies can also enhance their security and defence capabilities. At the same time, private investment is becoming the key differentiator between success and failure. If Europe is to remain competitive, shape the values underpinning quantum innovation and fully reap the economic, security and other benefits of its own intellectual leadership, it must act with urgency, clarity, and unity.

This is the moment for Europe to lead. This strategy is not the destination, but an evolving framework – a blueprint in motion – for Europe's quantum future. It requires the collective commitment of the EU, Member States, industry, academia, and civil society at large. If successful, quantum technologies will power the next technological revolution and underpin EU competitiveness, and Europe will be at the forefront, shaping it on its own terms.

APPENDIX

Quantum Europe Strategy Actions Summary

Area 1: Quantum Research and Innovation Initiative
• Amend EuroHPC JU Regulation to extend its remit to all quantum technologies and, as a first step, transfer present Horizon Europe R&I quantum activities into the JU [Q3 2025] • Present the Quantum Act proposal [2026] • Pilot two Quantum Grand Challenges (Fault-Tolerant Quantum Computing and Quantum PNT systems) [2025–2027]
Area 2: Quantum Europe Infrastructures
• Publish EU Quantum Computing and Simulation Roadmap [2026] • Expand the number and capacity of EuroHPC-based quantum computing systems [2026 onwards] • Set up a monitoring framework for quantum computing [2026] • Deploy the first EU-interconnected experimental quantum terrestrial and space secure communication network [by 2030] • Publish a Quantum Communication Roadmap [2026] • Launch a pilot facility for the European Quantum Internet [2026] • Deploy a distributed system of gravimeters across Europe [2026 onwards] • Publish a Quantum Sensing Roadmap [2026] • Establish a European Q-MRI Pilot Infrastructure and scale it up across Europe [2025 onwards]
Area 3: The Quantum Europe ecosystem
• Establish six new quantum pilot production lines under the Chips Joint Undertaking [2025] • Launch a quantum design facility [2026] • Release a Quantum Chips Industrialisation Roadmap [2026] • Publish a European Quantum Standards Roadmap [2026] • Expand the network of quantum competence clusters [2026] • Carry out and finalise EU-wide assessments of supply chain vulnerabilities [2025–2026]
Area 4: Space & Dual Use Potential Quantum Technologies (Security & Defence)
• Sign a cooperation agreement with ESA for the development of a Quantum Technology Roadmap in space [Q2 2025] • Develop a quantum sensing space & defence technology roadmap [2026] • Contribute to the European Armament Technological Roadmap [Q4 2025] • Launch spin-in initiatives to bring-in civil companies and academia for defence applications [as of 2026, onwards]
Area 5: Quantum Skills
• Establish the European Quantum Skills Academy [2026] • Launch European Advanced Digital Skills Competitions in quantum [as of 2026, onwards] • Launch a Pilot Programme on Researcher-in-Residence in Quantum technology startups [2025] • Launch the European Quantum Mobility Programme [2026, onwards]
International Cooperation
• Launch bilateral and multilateral cooperation initiatives [2025 onwards] • Work with the Member States to establish European Quantum International Cooperation Framework [2025 onwards]