

QUANTUM COMPUTING

Technologies at a Glance

April 2026

"TECHNOLOGIES AT A GLANCE" REPORT

ANALYSING KEY TRENDS
FOR INFORMED
DECISION-MAKING



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Agenda

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Discover, in a nutshell, what quantum computing is, the key benefits it offers to companies, and why it demands our attention today.

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Quantum computing technologies.
The scientific pillars of quantum computing

03 Tech radar

A visual tool that categorizes and ranks quantum computing technologies based on their maturity (adopt, trial, assess, explore).

04 Deep dive on key technologies

Learn more about quantum computing's most mature technologies: Hybrid Quantum-Classical Frameworks (HQCF) and Quantum Annealing

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What is quantum computing?

Quantum computing is a new paradigm that harnesses the principles of **quantum mechanics**, such as superposition and entanglement. Unlike classical bits (0 or 1), quantum bits, or **qubits**, can exist in **multiple states simultaneously**. This enables the creation of a **multidimensional computational space** capable of **solving complex problems** that are currently unsolvable by traditional supercomputers.

Why now?

We have entered the "Quantum 2.0" era, transitioning from theoretical physics to engineering controllable systems. Recent breakthroughs in quantum hardware, software and algorithms have accelerated progress toward practical quantum computers. Governments and private-sector leaders are making significant investments in this technology, recognizing its disruptive potential. As countries position themselves to benefit from the next wave of digital transformation, acting now increases the likelihood of securing technological leadership and shaping global standards.

Recent milestones, such as Google's Willow chip achieving a 13,000x speed advantage and IBM's push toward fault-tolerant systems by 2029, show that the technology is moving from labs to deployment.

For what?

Quantum computers excel at specific high-complexity tasks: simulating molecular structures for drug discovery, optimising global logistics and refining financial risk modelling. They are designed to complement classical systems, resolving combinatorial and scientific explosions that exceed the memory and processing limits of any classical computer and supercomputer.

The year 2025 marked exactly one century since the initial formalisation of quantum mechanics, a period that has transitioned from theoretical discovery to the direct engineering of quantum systems.

Quantum computing is an area of rapid technological advancement with the potential to revolutionize industries, economies and society as a whole. As organisations around the world seek to maintain their competitive edge, understanding quantum computing and its implications has become essential.

Key drivers

- **Fundamental Capability:** Quantum computing uses the laws of subatomic physics to process data in a multidimensional state space. This enables a quantum computer to evaluate a vast number of possibilities simultaneously, making it exceptionally powerful for specific types of problem. Applications include scientific discovery simulation, solving complex optimisation problems, factoring large numbers, and cryptography.
- **Commercial Inflection Point:** The successful integration of quantum processing units (QPUs) with high-performance computing (HPC) environments into hybrid frameworks has created a viable pathway for near-term industrial application. These achievements, coupled with steady improvements in qubit coherence and scale, are accelerating the timeline for tangible commercial use cases.
- **Strategic Relevance:** Beyond raw speed, the technology provides a significant advantage in high-value sectors. For example, it can speed up domestic pharmaceutical research in response to health crises or help to design advanced materials for key industries. This technological self-sufficiency enables a nation to protect its data, drive its own economic innovation and maintain a competitive edge.

This report maps the core scientific principles, assesses the maturity of leading technology modalities, and provides deep dives into the most industrially relevant approaches for near-term adoption: **Hybrid Quantum-Classical Frameworks** and **Quantum Annealing**.

Quantum Computing

The scientific pillars

Quantum computing is built upon several counter-intuitive principles of quantum mechanics that have no direct classical analogue. Understanding these pillars is essential to grasp both the potential and the challenges of the technology.

Superposition



A qubit can be in a state of 0, 1, or both at the same time, which is called superposition. This means quantum computers can process a lot of possibilities all at once, rather than just one at a time.

Entanglement



Entanglement is a quantum-mechanical state where two or more qubits become linked in a perfectly correlated system, meaning the state of one cannot be described independently of the others. This connection is intentionally created by applying precise external fields, such as targeted microwave or laser pulses, which act as quantum gates to force the qubits into this shared state..

Interference



While a qubit is in superposition, it does not simply represent 0 and 1; rather, it has a probability amplitude associated with each state. Interference is the process by which a quantum algorithm manipulates these probabilities precisely, amplifying the amplitudes that lead to the correct answer (constructive interference) and cancelling out those that lead to incorrect ones (destructive interference). When the final measurement is made and the superposition collapses, the state with the highest probability — the correct answer — is observed.

Decoherence



Qubits are very sensitive and can lose their quantum properties easily when they interact with their surroundings. This process, called decoherence, introduces errors and limits the power of current quantum computers. Solving this problem is a major goal in quantum computing research.

10 key technologies

Quantum computing - Tech radar

ADOPT

1 Hybrid Quantum-Classical Frameworks: Combining classical high-performance computers with quantum processors is the most pragmatic approach for achieving value from quantum computing today. This model operates within the current "Noisy Intermediate-Scale Quantum" (NISQ) era.

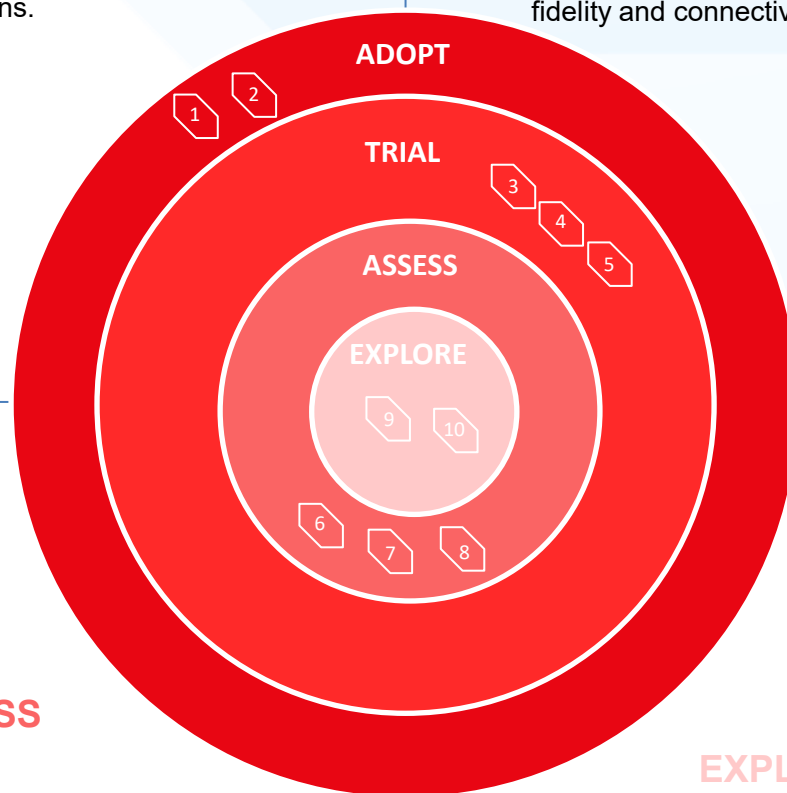
2 Quantum Annealing: A specialised type of quantum computing designed exclusively for optimisation problems. It is the most mature modality for specific commercial applications.

TRIAL

3 Superconducting Gates: The dominant modality, used by Google and IBM. Qubits are tiny electrical circuits made from superconducting materials cooled to near absolute zero.

4 Quantum Simulation: Using a controllable quantum system to simulate another, less accessible one. This is a primary use case for NISQ computers, particularly in materials science and drug discovery.

5 Trapped Ion Systems: Qubits are individual ions held in place by electromagnetic fields. They offer high fidelity and connectivity but slower gate speeds.



Non-exhaustive list of quantum computing technologies

The primary target market for these quantum applications consists of research institutions and large, established corporations, particularly within industry leaders possessing complex optimisation, simulation, and machine learning challenges.

ASSESS

6 Neutral Atom Arrays: Atoms are trapped in a grid using lasers. This approach shows excellent scalability, with systems reaching over 1,000 qubits.

7 Photonic Computing: Qubits are encoded in photons (particles of light). These systems can operate at room temperature but face challenges in error correction and scalability.

8 Silicon Spin Qubits: Qubits are based on the spin of an electron embedded in a silicon-based device, leveraging mature semiconductor manufacturing techniques.

EXPLORE

9 Quantum Machine Learning (QML): A software field exploring how quantum computers can accelerate machine learning tasks. Currently in the research phase but with high potential.

10 Error-Corrected Qubits: A conceptual and experimental technology to create a stable, reliable "logical qubit" from many noisy physical qubits.

What is HQCF?

A **Hybrid Quantum-Classical Framework** model functions by integrating a quantum processing unit (QPU) as a specialised accelerator within a classical high-performance computing (HPC) environment.

Given the limitations of today's NISQ (Noisy Intermediate-Scale Quantum) processors, a purely quantum approach is not yet feasible for most real-world problems and **HQCF** remains the most viable and strategic path forward for the moment.

How it works?

In a hybrid workflow, a complex problem (e.g., simulating a new battery material or optimising a financial model) is broken down into smaller tasks. The majority of the tasks (data pre-processing, parameter setting and results analysis) are handled by the powerful classical HPC system. Only the core, computationally intractable part of the problem, the "quantum kernel", is sent to the QPU for processing. The QPU's results are then fed back to the classical computer, which iterates and refines the solution. This QPU is considered a "noisy" resource because qubits are extremely sensitive to their environment. Interactions with external factors, such as minute thermal fluctuations or electromagnetic fields, can corrupt their delicate quantum states in a process called decoherence. This "noise" introduces errors, limiting the duration and reliability of any calculation. The hybrid approach is therefore a pragmatic strategy designed to maximise the utility of these scarce and imperfect quantum resources; it leverages the reliability of classical HPC infrastructure while reserving the noisy QPU exclusively for the specific calculations that only it can perform.

Strategic Importance

This hybrid model is the cornerstone of national quantum strategies worldwide, and its successful implementation hinges on a sophisticated hardware architecture known as **Heterogeneous Computing**. Modern datacentres are evolving towards this "rack-scale computing" paradigm, where the entire server rack (i.e. Central Processing Units (CPUs), Graphics Processing Units (GPUs), and Quantum Processing Units (QPUs)) is engineered as a single, cohesive system. This physical integration is critical for maximising data throughput and energy efficiency, enabling the different processors to work together seamlessly.

This integrated approach physically realises the hybrid strategy, providing a pragmatic and cost-effective pathway for researchers and industries to build quantum-ready skills and explore early advantages.

04

Key technologies

Hybrid Quantum-Classical Frameworks

What are the concrete applications?

HQCF are already demonstrating concrete applications across multiple industries:

Pharmaceuticals & Healthcare: HQCF enable faster drug discovery through quantum-powered molecular simulations. It assists in protein folding prediction and medical imaging analysis, accelerating R&D cycles.

Finance: Hybrid algorithms are used for asset pricing, portfolio optimisation and risk analysis, handling complex market scenarios more efficiently than classical methods alone.

Chemistry & Materials Science: HQCF assist in modelling chemical reactions, catalysis and material design, offering greater accuracy in discovering new substances and improving manufacturing processes.

Logistics & Supply Chain: Route optimisation, dynamic scheduling and resource allocation benefit from hybrid approaches that provide enhanced solutions for complex, real-time decision-making.

Automotive & Aerospace: HQCF are used in aerodynamic simulations, battery materials optimisation and traffic pattern prediction, leading to design improvements and greater efficiency.

Machine Learning & AI: Hybrid frameworks accelerate training of machine learning models, enable quantum-assisted feature selection and improve data analytics in complex datasets.

Luxembourg's Key Player

In Luxembourg, the primary entity embodying this hybrid strategy is [LuxProvide](#), the national HPC and data competence centre. As the operator of the MeluXina supercomputer, LuxProvide is tasked with integrating the upcoming [MeluXina-Q](#) quantum accelerator. This positions LuxProvide as the central enabler for researchers and companies to access a world-class hybrid quantum-classical environment, driving the development of practical applications and a skilled workforce.

European Infrastructure Projects

- **EuroQCS (Quantum and Hybrid Computers for Europe):** A flagship initiative focused on deploying quantum and hybrid computers across Europe, including sites in France, Germany and Italy.
- **OpenSuperQPlus:** This project focuses on developing open superconducting quantum computers and is a critical contributor to the EuroQCS hybrid roadmap.
- **HPCQS:** Works to integrate 100-qubit quantum simulators into existing European supercomputing centres to provide researchers with hybrid compute power.

What is Quantum Annealing?

Quantum Annealing is a specialised branch of quantum computing designed to solve complex optimisation problems currently beyond the reach of classical systems. Instead of running a sequence of programmed logical steps, annealers are engineered to physically guide a quantum system towards its lowest energy point.

The key advantage of quantum annealers lies in their unique ability to 'tunnel' through energy barriers in a solution space, allowing them to escape local minima that frequently trap classical "simulated annealing" solvers.

How it works?

The process starts by initialising qubits in a simple, known low-energy configuration. The system is then slowly transformed (or "annealed") into a new configuration that represents the complex problem to be solved. According to the adiabatic theorem of quantum mechanics, if this transition is slow enough, the system will remain in its lowest energy state throughout the process. At the end of the evolution, the final state of the qubits provides the solution to the optimisation problem.

What are the concrete applications?

Quantum annealing is the most commercially mature quantum computing technology. D-Wave Systems is the leading provider, having developed and sold quantum annealers for over a decade. Their systems are accessible via the cloud and have been used by companies like Volkswagen for traffic flow optimisation and by financial institutions for portfolio optimisation. While not universal quantum computers, annealers are a powerful tool for a specific but highly valuable class of business problems, offering a more direct path to potential ROI than gate-based machines.

Deployments in manufacturing scheduling (Ford Otosan) and maritime logistics (Port of Los Angeles) have demonstrated feasible solutions in under five minutes for tasks previously intractable classically.

04

Key technologies

Quantum Annealing

Real-world deployments of quantum annealing have transitioned from small-scale proofs-of-concept to industrial-scale solvers:

Manufacturing Scheduling: Ford Otosan utilised a hybrid quantum-classical annealer to manage 16,000 constraints for production line scheduling. The system generated feasible schedules in under five minutes, a task that was previously intractable for classical systems within a reasonable operational timeframe.

Logistics & Cargo: Amerijet International and Quantum-South demonstrated that quantum-optimised container loading could increase aircraft payload by 30% and volume by 76% across 451 tested flights.

Maritime Logistics: At the Port of Los Angeles, quantum annealing was applied to synchronize crane movements and truck arrivals, resulting in a 10% increase in throughput for the world's busiest container terminal.

Strategic European Projects

- **PASQuanS2.1 (Programmable Atomic Large-scale Quantum Simulation 2.1):** This project utilises large-scale quantum simulators to solve optimisation problems by simulating complex physical laws.
- **QCFD (Quantum Computational Fluid Dynamics):** This initiative explores the application of quantum computing to fluid dynamics, a field involving high-complexity simulation and optimisation.

The field of quantum computing is advancing rapidly, with major players regularly announcing new breakthroughs in hardware and algorithmic. In October 2025, Google Quantum AI announced that its 105-qubit "Willow" processor had achieved "verifiable quantum advantage". Similarly, IBM continues to push its ambitious roadmap, aiming to deliver "quantum advantage" by 2026 and a fault-tolerant system by 2029. These developments underscore a clear trend: the path to quantum value is an incremental one. The next 3-5 years will be defined by the exploration of "quantum advantage" on NISQ machines via hybrid frameworks.

The global quantum computing market is projected to reach 20 billion by 2030, with early adopters capturing up to 2 trillion in economic value by 2035.

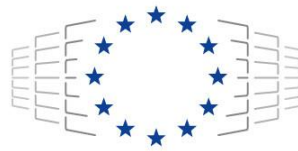
Despite this momentum, significant risks remain that could affect the timeline for implementation. Technical obstacles (high error rates, qubit instability), a shortage of key talent and rising geopolitical tensions could hamper international collaboration and lead to the introduction of export controls on these technologies, which are deemed critical.

For Luxembourg, the strategy is clear: by integrating MeluXina-Q into the national supercomputing infrastructure and fostering the creation of an ecosystem through the 2026 Joint Call for projects, the country is securing its place in a future where "fluid intelligence" (i.e. the ability to solve complex and unprecedented problems) will be powered by quantum-accelerated architectures. The transition from experimental prototypes to production-ready systems is expected to occur between 2029 and 2035, with early adopters in finance, logistics, healthtech and materials science capturing considerable economic value.

For Luxembourg-based companies, it is imperative to start preparing for the quantum era today: assessing the relevance of quantum applications to their business challenges and strengthening the technical skills of their talent.

Explore [our Market applications report](#) on our knowledge hub to discover concrete market applications and illustrations where early commercial traction is already emerging and where future growth may be most impactful.

- **Government of Luxembourg:** [Joint Call Data-AI-Quantum 2026](#), [Luxembourg's AI Strategy 2025](#), [Accelerating Digital Sovereignty 2030](#)
- **Luxinnovation Knowledge Hub:** [Quantum technologies](#)
- **LuxProvide:** [MeluXina-AI](#), [MeluXina-Q](#)
- **uni.lu SnT:** [Quantum Computing](#)
- **MIT:** [What is quantum computing?](#), [Quantum Index Report 2025](#)
- **Uchicago:** [TRL Levels of Quantum Modalities \(2026\)](#)
- **QT.EU:** [European Quantum Flagship Project Database](#)
- **Google:** [Quantum AI](#).
- **BCC:** [Quantum market growth 2030](#)
- **CSIS:** [Practical Areas of Quantum](#), [QC: Applications and Implications 2023](#)
- **EuroHPC:** [Hosting Agreements for Quantum](#)
- **IBM:** [IBM Quantum Innovation Roadmap 2024](#)
- **Markets and Markets:** [Global Quantum Forecast 2030 \(2025\)](#)
- **McKinsey & Company:** [Quantum Technology Monitor 2024](#) and [2025](#)
- **US DSI:** [Latest developments in QC](#)
- **World Economic Forum:** [Quantum Technologie - Key Opportunities](#)
- **Innovation News Network:** [Why quantum computing is advancing rapidly, 2025](#)
- **Techtarget:** [Quantum computing – challenges and opportunities 2025](#)



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