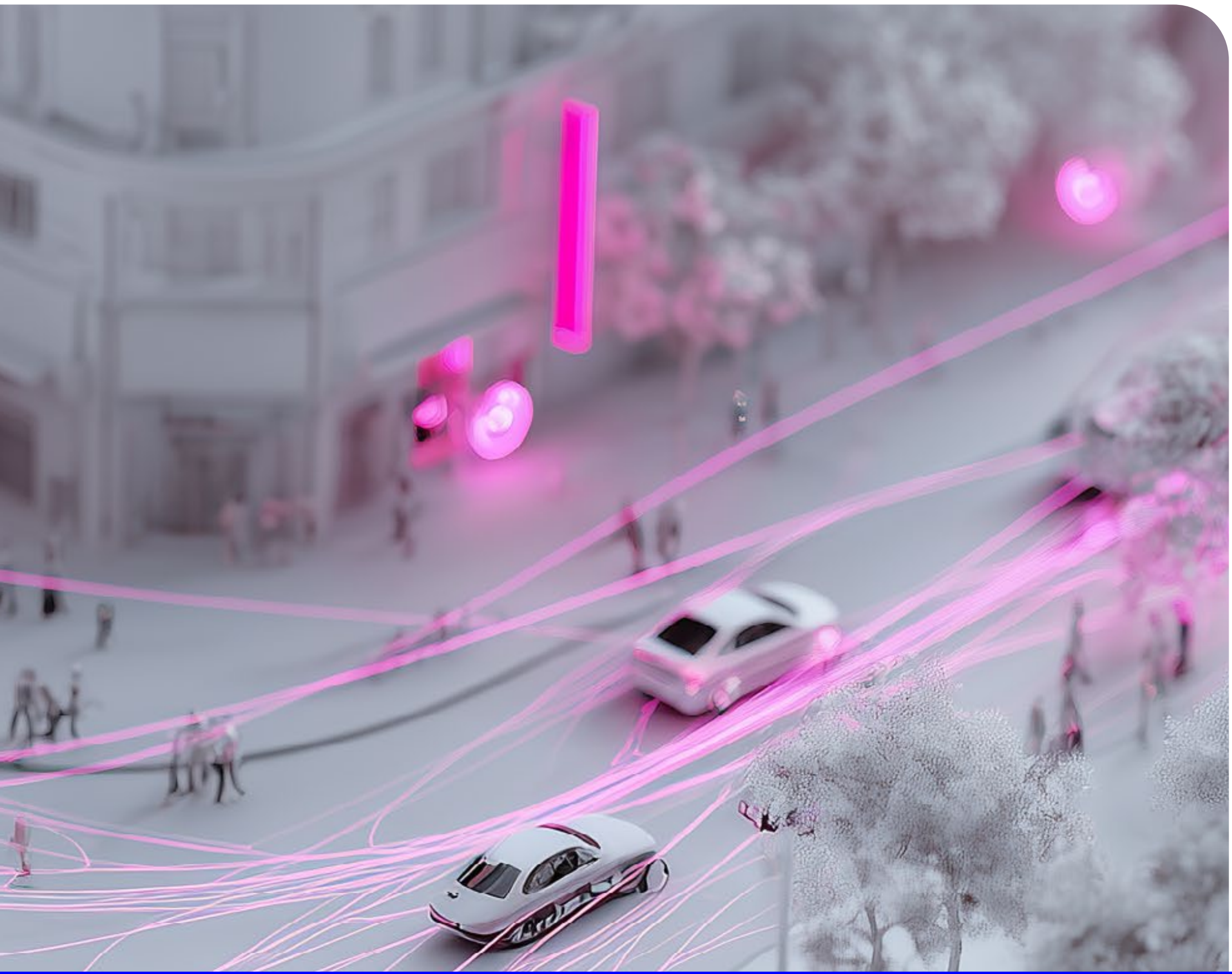

Quantum in action: practical plays defining what’s next

A practical guide for business and IT leaders

Introduction

Quantum is no distant concept reserved for research labs or conference keynotes. **Quantum is becoming very tangible for organisations like yours.** If you're looking for use cases of quantum systems, relevant for your sector or industry, then we invite you to read on.

This paper is meant to help you do that. You will discover how quantum may help in finance, energy, healthcare, logistics, manufacturing, telecom, mobility, and other sectors, through use cases that speak the language of business, operations, security, and innovation.

Some of these examples focus on **optimisation**: routing vehicles, improving supply chains, balancing energy grids, scheduling production, or managing portfolios.

Others highlight **simulation**, where quantum can help accelerate materials discovery, battery innovation, chemistry, or drug development.

You will also see how quantum-safe security, quantum communication, and quantum sensing could support use cases ranging from protected transactions and critical infrastructure to imaging, navigation, and advanced industrial monitoring.

Our purpose is to help you recognise patterns, connect them to your own reality, and ask yourself: **where could quantum create upside for my business**, the value chain I'm part of, or my entire sector?

While reading, reflect on the examples that feel closest to your operational challenges, strategic ambitions, or innovation roadmap. Which ones might justify a first internal discussion or conversations with partners for the Quantum Circle community?

And if you have already started that journey, **share your first experiences with us in the Quantum Circle community**. The best way to make quantum real is to learn from each other and turn curiosity into action together.

Jan Sonck
Community & Quantum Innovation Lead

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Automotive & Mobility

1
Smoother cities: how quantum computing can unclog urban traffic

Urban mobility is under pressure. Congestion is costing cities billions in lost productivity, harming the environment, and lowering the quality of life. But what if traffic didn't just react? What if it anticipated, adapted, and optimised in real-time?

This is the promise of quantum-powered traffic management. As cities grow more complex, quantum computing offers a new frontier for orchestrating the flow of people and goods with unprecedented precision. In this article, we dive into how quantum algorithms are already reshaping how traffic is managed and why this matters for businesses, city planners, and citizens alike.

Case: **Traffic flow optimisation with quantum computing**

Traffic optimisation involves many variables that shift in real-time: vehicle density, road conditions, and signal timing. Classical computers cannot process this complexity at the required scale. Quantum algorithms can analyse many options simultaneously and deliver more effective coordination across entire city networks.

Automotive & Mobility

Business value

- **Reduced congestion and shorter journeys:** Quantum models can create better traffic light sequences and routing, which shortens travel times for commuters and logistics.
- **Lower emissions and fuel consumption:** Smoother traffic reduces unnecessary idling and stop-and-go driving, which lowers fuel use and supports cleaner air goals.
- **Improved urban mobility and citizen satisfaction:** An efficient flow of traffic makes public transport more reliable, deliveries more predictable, and city life less stressful.
- **Enhanced planning for infrastructure:** Simulations provide insights that help city planners design smarter roads, public transport lines, and cycling routes.

Technology readiness

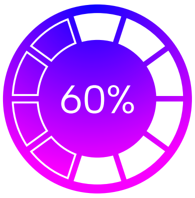
Quantum traffic optimisation is moving beyond theory into practical testing. Several pilot projects have already been run in large cities using hybrid quantum-classical models. These approaches use classical systems to process real-time traffic data and quantum computers to optimise the most complex parts of the problem. The results are promising but still limited to controlled scenarios and small-scale networks. Over the next five to ten years, wider adoption will depend on scaling quantum hardware and integrating it smoothly into existing traffic management platforms.

Leading players and experiments

Volkswagen has tested quantum-based traffic flow pilots with D-Wave, including projects in Beijing and Lisbon, where they modeled thousands of taxis to reduce travel times during peak hours.

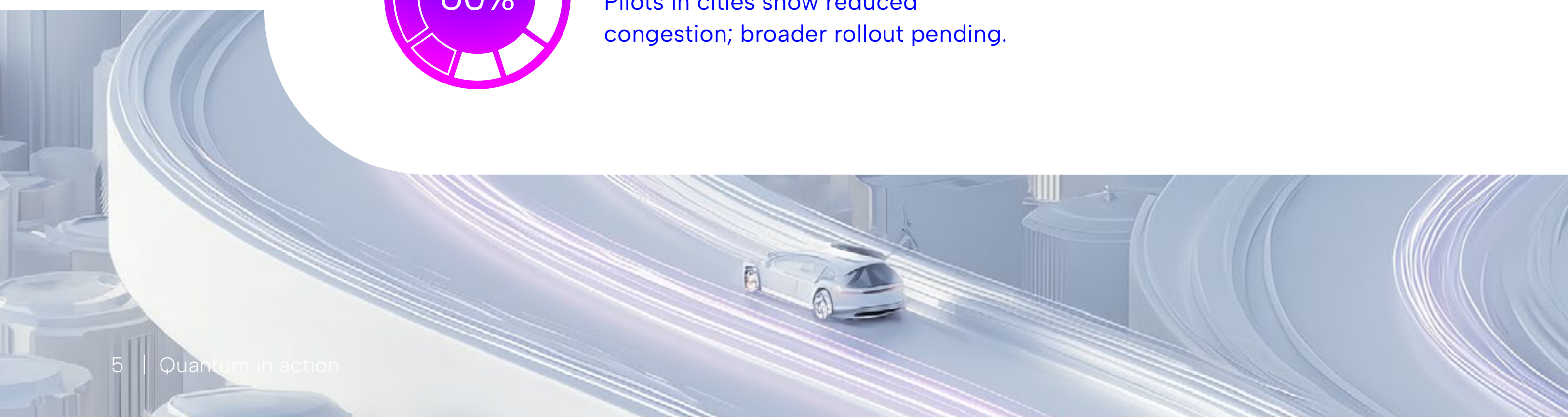
Toyota is investing in research on how quantum algorithms can support large-scale mobility planning, from routing to logistics optimisation.

IBM and **D-Wave** are offering quantum platforms that researchers and municipalities use to experiment with new traffic management models, helping scale pilot projects into practical applications.

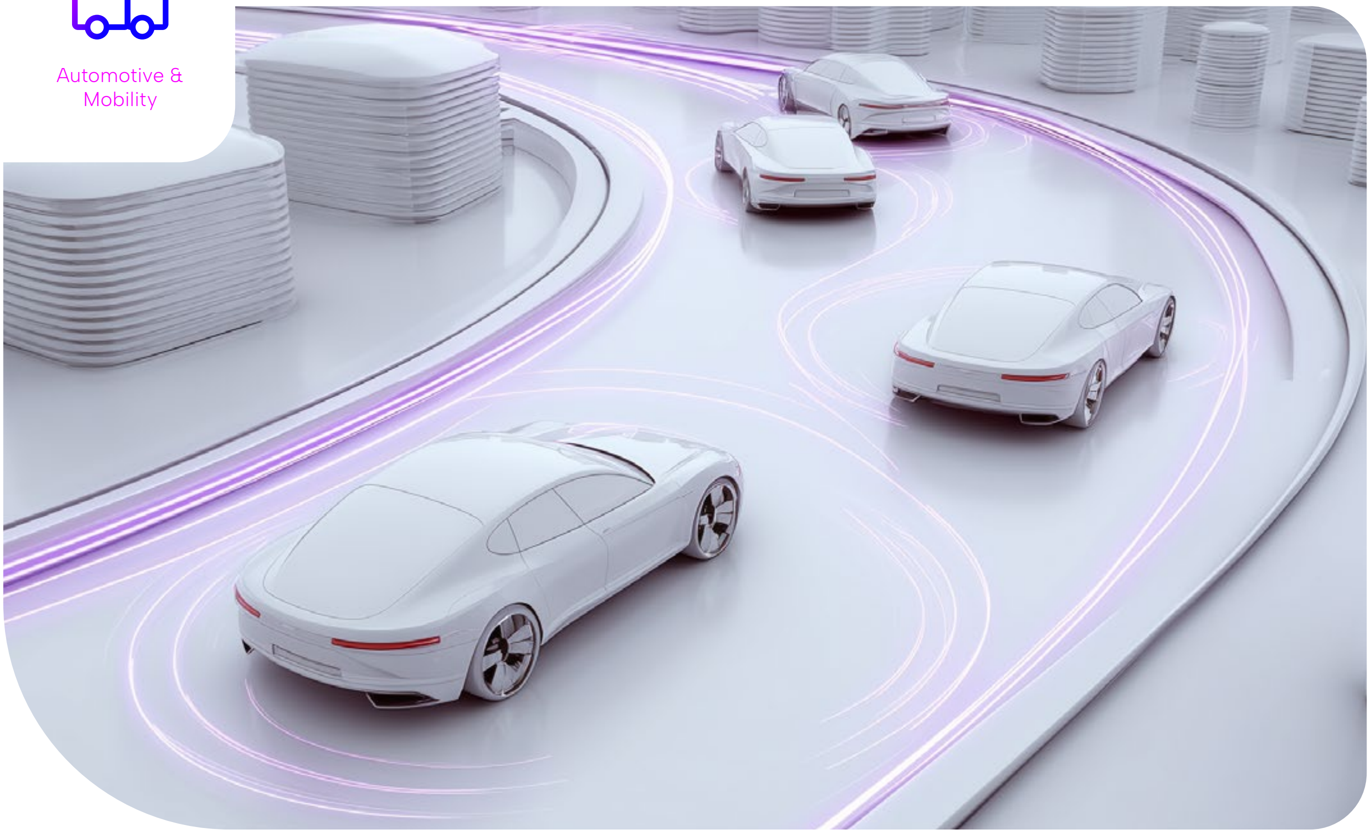


Maturity barometer

Pilots in cities show reduced congestion; broader rollout pending.



Automotive & Mobility



2

Quantum eyes on the road: making autonomous vehicles more reliable

Autonomous vehicles promise safer roads and more efficient mobility but only if they can see, sense, and decide with near-perfect accuracy. Traditional sensors struggle in complex environments like tunnels, bad weather, or crowded cities. Enter quantum sensing: a breakthrough technology that brings unprecedented precision to how self-driving cars perceive the world around them.

This article explores how quantum-enhanced sensor fusion could be the game-changer for autonomous mobility and what it will take to bring it from lab to road.

Case: **Autonomous vehicle sensor fusion with quantum sensing**

Autonomous vehicles rely on accurate information about their surroundings. Quantum sensors can provide ultra-precise measurements of position, acceleration, and orientation. When combined with lidar, radar, and cameras, these sensors make autonomous driving more reliable, even in challenging environments.

Business value

- **Increased safety and reliability:** Quantum sensors add precision to navigation, reducing the risk of errors that could lead to accidents.
- **Enhanced performance in difficult conditions:** Vehicles can perform better in fog, tunnels, or areas with poor GPS signals.
- **Reduced reliance on external infrastructure:** Cars can operate more independently without depending as much on satellites or external positioning systems.
- **Competitive advantage:** Early adopters of quantum sensing will gain a stronger position in the race for safe and reliable autonomous mobility.

Technology readiness

Quantum sensors are currently in the prototype stage. Laboratory experiments have shown that they can achieve precision levels far beyond today's sensors, but most devices are still too large or sensitive to be installed in vehicles.

Field trials are starting to test ruggedised versions under real driving conditions, focusing on stability and reliability in challenging environments like tunnels or dense urban centers. Commercial use in vehicles is likely still a decade away, but progress is accelerating thanks to strong investment from both research institutes and automotive companies.

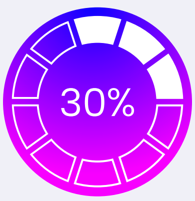
Leading players and experiments

Bosch is actively developing quantum sensors that could improve navigation precision in vehicles, with the goal of reducing reliance on GPS.

Toyota is exploring how quantum sensing technologies can strengthen autonomous systems, ensuring reliable navigation in complex urban settings.

Qnami, a Swiss startup, provides quantum sensing technologies based on nitrogen-vacancy centers in diamonds, which could be applied in autonomous navigation.

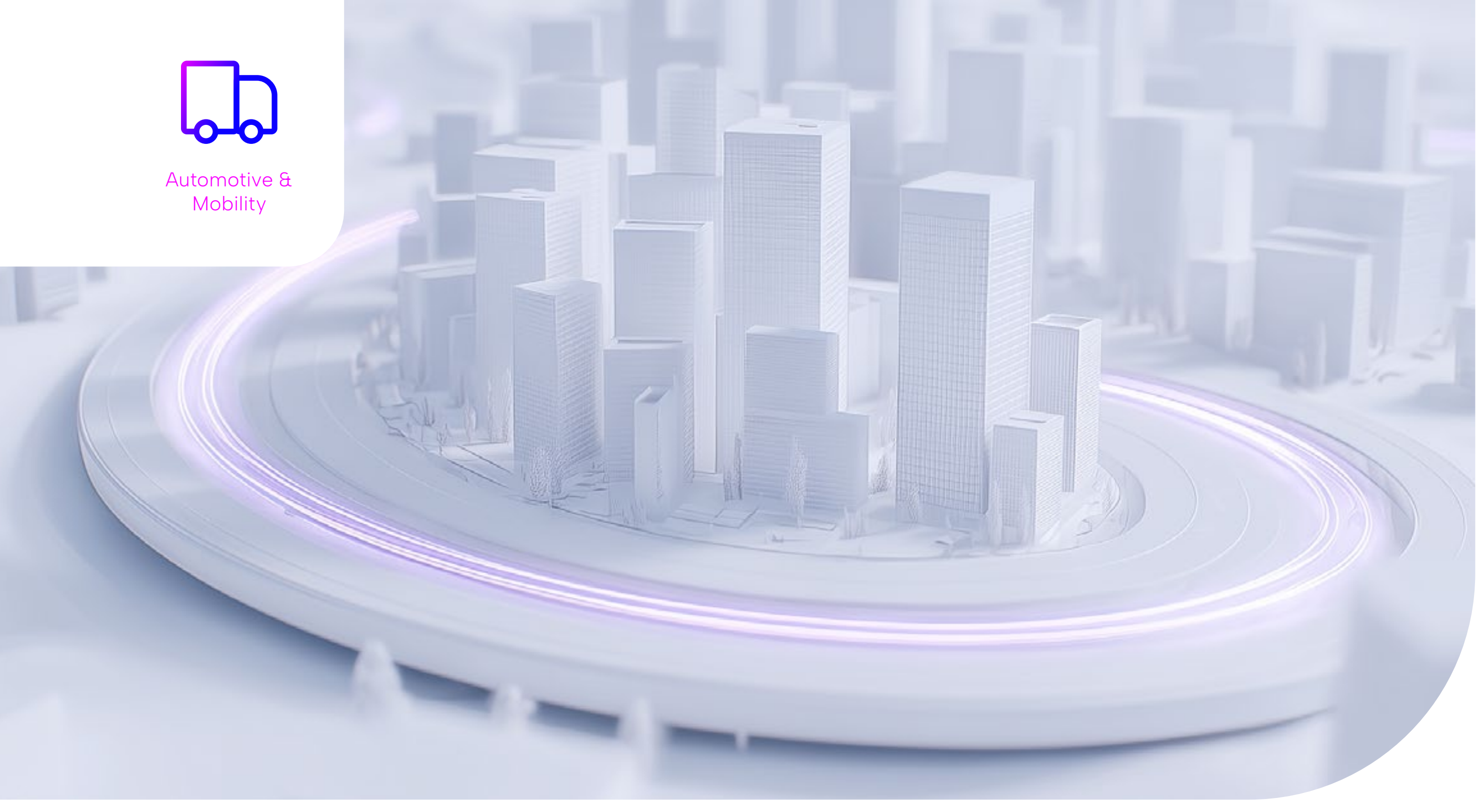
Fraunhofer Institute in Germany is conducting applied research on quantum-enhanced navigation, testing prototypes, and working on integration pathways for automotive applications.



Maturity barometer

Prototype phase; promising for navigation in complex environments.

Automotive & Mobility



3

Quantum-proofing the roads: securing vehicle communication for the future

In this article, we explore why PQC matters for the future of automotive cybersecurity and how industry leaders are preparing now to secure the roads of tomorrow.

Connected cars are transforming transportation, enabling cooperative driving, collision avoidance, and real-time updates. But as connectivity grows, so does the risk of cyber threats. With the rise of quantum computing, current encryption standards may soon become obsolete. The solution? Post-quantum cryptography (PQC): designed to withstand even the most powerful quantum attacks.

Case: **Secure vehicle-to-vehicle communication with post-quantum cryptography**

Cooperative driving and collision avoidance depend on secure communication between vehicles. As quantum computers become more powerful, today's encryption methods risk being broken. Post-quantum cryptography ensures that vehicle-to-vehicle communications remain secure against future threats.

Business value

- **Future-proof security:** Quantum-safe encryption protects vehicles from cyber risks that could emerge in the next decade.
- **Compliance with regulations:** New laws are emerging to enforce higher standards in cybersecurity, and PQC helps meet them.
- **Protection against malicious interference:** Secure communication prevents hackers from disrupting traffic systems or sending false signals.
- **Trust in cooperative systems:** Drivers and passengers gain confidence that connected vehicle networks are safe and reliable.

Technology readiness

Post-quantum cryptography is further along than many other quantum technologies because it relies on software rather than new hardware. The National Institute of Standards and Technology (NIST) is finalizing PQC standards, and automotive suppliers are beginning to test how these algorithms fit into vehicle communication systems. Pilot projects are underway to integrate PQC into vehicle-to-vehicle and vehicle-to-infrastructure protocols. While full deployment will take time, the automotive sector is expected to adopt PQC within the next five to seven years to stay ahead of cybersecurity risks.

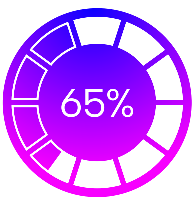
Leading players and experiments

Volkswagen and BMW are both investigating how post-quantum cryptography can be integrated into connected car systems, ensuring future-proof communication between vehicles.

PQshield, a UK-based company, develops cryptographic solutions designed to withstand quantum attacks and is already collaborating with industries where long-term data protection is essential.

Thales provides PQC technologies for critical infrastructure and is extending its expertise into automotive cybersecurity.

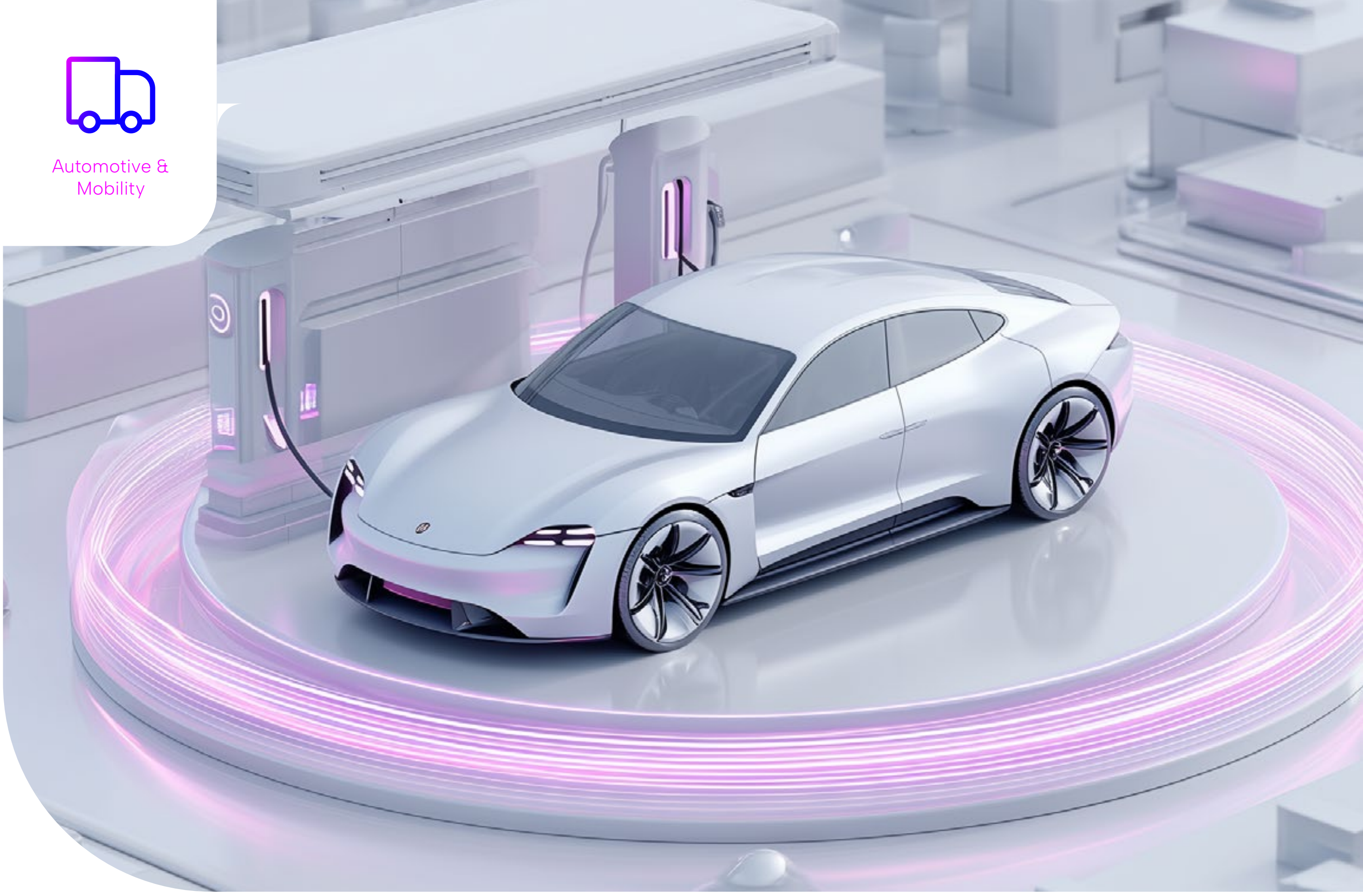
The European Commission funds multiple research initiatives to prepare Europe's mobility systems for a quantum-secure future, supporting collaborations between academia, industry, and policymakers.



Maturity barometer

PQC standards maturing; early automotive trials in V2X and secure comms.

Automotive & Mobility



4
Quantum batteries: accelerating electric mobility with material simulation

This article dives into how quantum is reshaping materials R&D, and why early adopters are already seeing real value.

The future of mobility is electric, but batteries are still a bottleneck. To extend range, cut charge times, and improve safety, we need materials that don't exist yet. That's where quantum simulation comes in. By modeling materials at the atomic level, quantum tools can dramatically accelerate battery innovation, unlocking the next generation of energy storage for EVs.

Case:
Battery and material innovation with quantum simulation

The transition to electric mobility depends on better batteries. Quantum simulation can model materials at the atomic level to accelerate breakthroughs in battery design. This includes safer solid-state electrolytes and higher-capacity anodes.

Business value

- **Faster development of advanced batteries:** Simulations speed up discovery cycles, reducing the time needed to test new materials.
- **Improved energy density and charging:** New designs can deliver longer driving ranges and shorter charging times.
- **Reduced R&D costs:** Companies spend less on trial-and-error experiments by predicting material performance more accurately.
- **Support for electrification and sustainability:** Better batteries support climate goals and make electric vehicles more attractive to consumers.

Technology readiness

Quantum simulation is already being used in research environments to model materials at the atomic scale. While current quantum hardware is limited, hybrid approaches combine quantum algorithms with classical high-performance computing to deliver useful insights. Several automotive and chemical companies are building pilot projects to explore solid-state electrolytes and high-capacity anodes. Widespread use in commercial R&D workflows will depend on the maturity of quantum platforms, which is expected to grow steadily in the next five to ten years. Early adopters are already gaining a head start by embedding quantum tools into their material discovery pipelines.

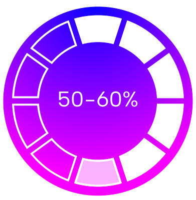
Leading players and experiments

Volkswagen and Ford are partnering with quantum software providers to accelerate materials research for electric vehicle batteries, aiming to develop longer-lasting and safer energy storage.

IBM and Microsoft offer cloud-based quantum platforms that enable automotive r&d teams to simulate complex chemical processes at the atomic level.

BASF, a global leader in chemistry, is exploring how quantum simulations can unlock new materials for automotive use.

Quantum Motion, a UK-based startup, is working on hardware that could power large-scale simulations for materials discovery, with applications in battery innovation.



Maturity barometer

Pilots in scheduling and process control show tangible efficiency gains.

Conclusion to the Automotive & Mobility series

The future of mobility will not be defined by incremental upgrades but by bold leaps. Quantum technologies are opening doors to entirely new ways of moving people and goods. Imagine cities where congestion is anticipated and dissolved before it forms, vehicles that navigate seamlessly even without satellites, and networks of cars that communicate securely in real-time. Electric vehicles will drive further, charge faster, and rely on batteries designed with quantum precision.

This is not distant science fiction. **The first pilots are already underway**, proving the business case and laying the foundation for global transformation. The real question is who will lead the charge.

Belgium, with its strong research base, thriving startup culture, and collaborative ecosystem, is ready to claim a central role in shaping this future. By uniting business, technology, research, society, and ecosystems, we can ensure that the quantum shift in mobility is not only innovative but also inclusive and impactful.

Discover more use cases on **quantumcircle.eu**

Chemicals & Materials

5
Smarter materials: how quantum simulation is transforming material discovery

Modern industry runs on advanced materials, but the pace of discovering them hasn't kept up with the speed of global demand. Whether it's high-performance polymers, ultra-efficient batteries, or sustainable construction materials, designing new substances has long relied on trial-and-error, expensive lab experiments, and classical simulations that fall short.

Quantum computing offers a radical alternative. By simulating molecular and material behavior at the quantum level, researchers can predict properties, reactions, and performance before materials are even made. This means less guesswork, faster results, and entirely new classes of materials tailored for real-world applications.

In this article, we explore how quantum simulation is changing the way we discover and engineer the building blocks of tomorrow's industries and why it matters across sectors like energy, electronics, and aerospace.

Case: **New material discovery with quantum simulation**

Every molecule, every material, and every chemical reaction is governed by quantum physics. That's what makes materials science such a natural fit for quantum simulation.

Today's classical computers struggle to accurately simulate the behavior of even small molecules due to the exponential complexity of quantum interactions. But quantum computers can represent these interactions natively, allowing them to model the electronic structure of molecules and solids with far greater fidelity.

This opens up powerful new capabilities, including:

- Predicting the performance of novel materials before they're synthesised
- Exploring new classes of materials such as superconductors and quantum dots
- Modeling phase transitions, stability, and reactivity under various conditions
- Designing tailored materials for specific functions in electronics, batteries, or coatings

Quantum simulation dramatically accelerates the development of high-impact materials, especially those required to meet the world's energy, climate, and industrial innovation goals.

Business value

- **Accelerated innovation cycles:** Quantum simulation reduces the need for lengthy experimental trials, speeding up the R&D process from years to months.
- **Lower R&D costs:** By simulating molecular behavior before lab testing, companies can cut down on material waste, lab time, and costly trial runs.
- **Competitive advantage:** Discovering proprietary materials gives companies a strategic edge in high-value markets like aerospace, electronics, and biotech.
- **Sustainability breakthroughs:** Quantum tools help design lighter, stronger, and more energy-efficient materials, supporting the transition to greener technologies.

Technology readiness

Quantum simulation is already demonstrating early promise in academic and industrial research settings. While today's quantum hardware is still limited in scale, hybrid quantum-classical workflows are actively being tested in pilot projects.

Notably, quantum computers have achieved demonstrated quantum advantage in simulating small molecules, a key milestone toward more complex material systems. These hybrid approaches integrate quantum insights with classical HPC systems to unlock useful simulations even before fault-tolerant quantum computing arrives.

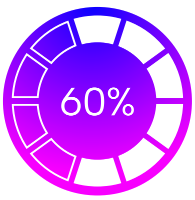
Over the next five to ten years, the ability to model increasingly complex materials will grow alongside advances in qubit fidelity, error correction, and software optimisation.

Leading players and experiments

BASF, **Dow**, **Merck** are collaborating with quantum startups and platforms to simulate molecular systems and accelerate the discovery of specialty chemicals and polymers.

IBM, **Microsoft**, and **Google** are offering quantum chemistry simulation tools via cloud platforms, enabling researchers to test quantum algorithms and scale hybrid workflows.

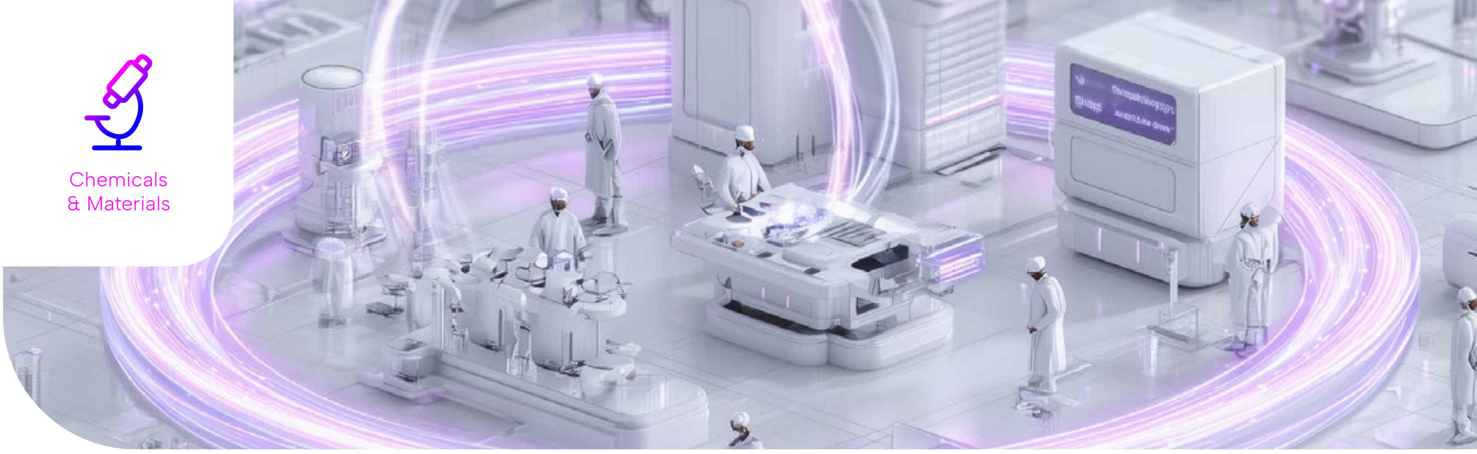
Mitsubishi Chemical and **TotalEnergies** are actively exploring quantum chemistry applications as part of their long-term innovation strategies.



Maturity barometer

Hybrid workflows in use; early pilots with small molecules.

Chemicals
& Materials



6
Catalysts of change: how quantum computing is designing cleaner chemistry

Catalysts are the invisible enablers of modern chemistry. They speed up chemical reactions without being consumed, making everything from fertilizers to fuels, plastics to pharmaceuticals, not only possible, but efficient. But designing the right catalyst is one of the most complex challenges in chemistry. It's a process often guided by trial, error, and expensive experimentation.

Quantum computing is poised to change that. By simulating catalytic reactions at the atomic level, quantum algorithms offer deep insights into the fundamental mechanisms that govern reactivity, selectivity, and efficiency. This could open the door to **tailor-made catalysts** for greener, faster, and more sustainable industrial processes.

Case: Catalyst design with quantum computing and simulation

Catalysts work by lowering the energy barrier of chemical reactions, but understanding how and why they do this, at a fundamental level, has long been limited by the constraints of classical simulation tools. Identifying active sites, reaction intermediates, and transition states with high precision requires simulating quantum mechanical interactions between electrons, something classical computers struggle to do at industrial scale.

Quantum computing offers a new approach. By modeling the behavior of electrons and atoms during catalytic processes, researchers can simulate:

- The entire reaction pathway, from reactants to products
- The structure and electronic properties of catalytic surfaces
- How catalysts interact with molecules under different conditions
- Why certain materials promote higher selectivity or yield

These insights help scientists design and validate new catalysts digitally, before entering costly pilot or production phases.

Applications range from green chemistry and sustainable fuels to low-emission petrochemicals and industrial-scale environmental remediation.

Business value

- **Improved process efficiency and selectivity:** Quantum simulation helps identify catalysts that boost yields while minimizing byproducts.
- **Lower energy consumption and emissions:** More efficient catalysts reduce the need for high temperatures or pressures, cutting energy use and carbon output.
- **Cost savings through better performance:** Optimised catalysts reduce waste, shorten production times, and extend equipment lifespan.
- **Accelerates green chemistry innovation:** Quantum-powered catalyst discovery supports the industry's shift toward sustainable and circular chemical production.

Technology readiness

Catalyst design is emerging as one of the most promising real-world applications of quantum simulation. While hardware is still developing, **early-stage research and pilot collaborations** are already underway.

Hybrid quantum-classical approaches are currently used to simulate smaller catalytic systems, focusing on the hardest-to-model parts of the reaction cycle. These pilots are laying the groundwork for broader adoption as quantum platforms scale in power and reliability.

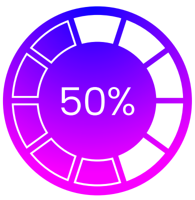
Over the next five to eight years, chemical companies are expected to increasingly integrate quantum simulation into their R&D workflows, particularly as sustainability and efficiency become business-critical.

Leading players and experiments

BASF and **Evonik** are working with quantum software providers to simulate catalytic mechanisms and develop next-generation industrial catalysts.

Cambridge Quantum and **Zapata Computing** are developing specialized quantum algorithms for chemical reactions, including tools focused on catalytic cycle modeling.

National labs and academic consortia in Europe, the US, and Asia are conducting foundational research into quantum catalysis, often in collaboration with both startups and industrial partners.



Maturity barometer

Early pilots using quantum simulation for catalytic cycles; promising for green chemistry and industrial efficiency.

Chemicals & Materials

7
Smarter chemistry: how quantum computing is optimising industrial processes

In the chemicals and materials sector, efficiency isn't just a metric, it's a competitive advantage. From production lines to global supply chains, every process must balance complexity, cost, and constant change. But traditional computing systems often hit a wall when faced with the scale and variability of real-world operations.

Quantum computing offers a new approach. By solving complex optimisation problems far beyond the reach of classical systems, quantum algorithms are helping manufacturers improve throughput, reduce waste, and respond more nimbly to shifting market conditions.

In this article, we look at how quantum computing is unlocking smarter, faster industrial processes and why it's becoming a key pillar of digital transformation in the chemical industry.

Case: **New material discovery with quantum simulation**

Chemical manufacturing involves thousands of interconnected variables: raw material availability, equipment capacity, maintenance schedules, shipping constraints, energy use, safety requirements, and more. Optimising across all of these dimensions, in real-time, is one of the industry's most persistent challenges.

Traditional optimisation tools can't always handle this scale of complexity. That's where quantum computing steps in. Quantum algorithms, particularly in combinatorial optimisation, can evaluate exponentially more possibilities than classical methods. This allows them to:

- Optimise scheduling across entire production networks
- Balance resource allocation dynamically
- Improve supply chain routing and inventory forecasting
- Respond to real-time data and disruptions with adaptive process control

Instead of static planning, quantum-enabled optimisation makes **agility a core capability**, helping chemical manufacturers stay efficient, resilient, and competitive in a volatile global landscape.

Chemicals
& Materials

Business value

- **Increased production efficiency and yield:** By optimising schedules, inputs, and process flows, manufacturers can run closer to peak performance.
- **Reduced operational costs and downtime:** Fewer delays, better coordination, and smarter maintenance planning lead to significant cost savings.
- **Enhanced supply chain resilience:** Quantum models can adapt to disruptions more effectively, from raw material shortages to logistics delays.
- **Greater agility in a dynamic market:** Real-time optimisation enables faster responses to changing demand, regulation, or energy pricing.

Technology readiness

Quantum-powered optimisation is one of the most mature applications in the field. Pilots and proofs-of-concept are already being deployed, often using **hybrid quantum-classical workflows** that combine classical data systems with quantum solvers for the most complex subproblems.

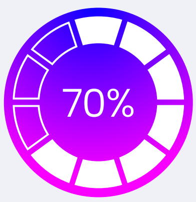
These projects are showing early success in areas like scheduling, warehouse management, and logistics. As quantum hardware improves in scale and stability over the next five to seven years, industrial-scale adoption will accelerate — particularly in sectors like chemicals, where even small efficiency gains can yield massive value.

Leading players and experiments

Dow and **BASF** have launched pilot projects using quantum platforms to streamline production workflows and resource planning.

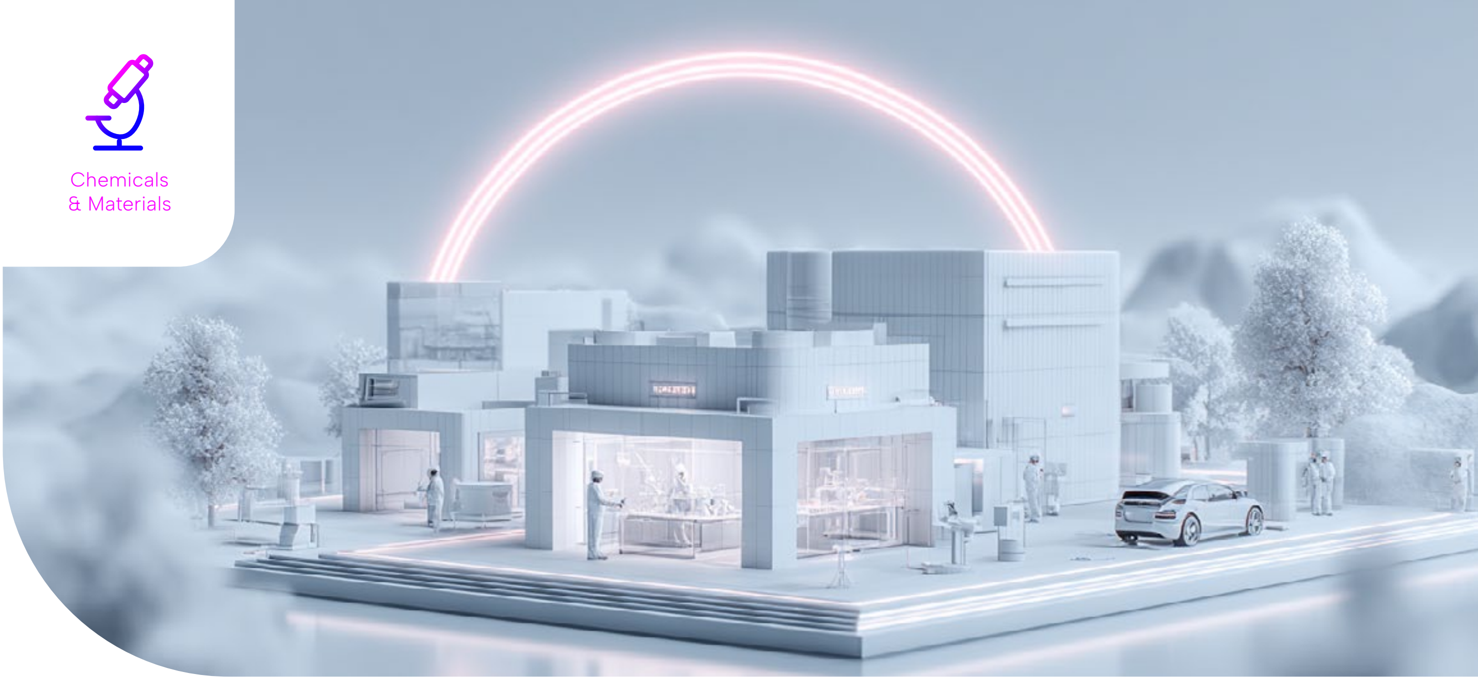
D-Wave and **IBM** are offering cloud-based quantum optimisation tools, enabling manufacturers to test use cases like energy efficiency and predictive maintenance.

Mitsubishi Chemical and **Siemens** are experimenting with quantum-enhanced process control systems, aiming to improve agility and decision-making on the factory floor.



Maturity barometer

Pilots in scheduling and process control show tangible efficiency gains.



Chemicals & Materials

8
See the invisible: monitor materials with quantum precision

In chemical and materials manufacturing, what you can't see can cost you. From undetected contaminants to minor process deviations, even the smallest invisible variable can lead to compromised product quality, unplanned downtime, or safety risks.

Quantum sensors offer a new level of precision, one that sees deeper, reacts faster, and unlocks insights that classical instruments simply miss. By detecting magnetic, chemical, and physical changes at the quantum level, these sensors make it possible to monitor industrial processes with unprecedented sensitivity.

In this blog, we explore how quantum sensing is already transforming quality assurance, safety, and efficiency in the materials sector and how early adopters are gaining a measurable edge.

Case: **Advanced sensing with quantum sensors**

Traditional sensors are already central to industrial automation. But in high-stakes chemical processes, conventional systems can't always capture the subtle variables that matter most, particularly under extreme conditions like high heat, pressure, or reactivity.

Quantum sensors take advantage of phenomena like **quantum entanglement** and **superposition** to detect incredibly small changes in a material's state. They can:

- Measure magnetic fields, pressure, or temperature with atomic-level precision
- Detect trace contaminants or deviations in chemical composition
- Monitor reaction conditions in real-time — even during highly dynamic processes
- Ensure consistent product quality across production batches

This makes them invaluable for real-time process control, predictive maintenance, and advanced quality monitoring, especially in environments where precision directly affects safety, compliance, or cost.

Business value

- **Improved product quality and consistency:** High-precision monitoring ensures tighter control over material properties and production variables.
- **Early detection of process deviations:** Quantum sensors can identify anomalies before they cause defects or safety issues.
- **Enhanced safety and regulatory compliance:** More accurate monitoring supports compliance with strict environmental, safety, and purity standards.
- **Supports Industry 4.0 transformation:** Quantum sensing integrates with digital systems to enable smarter, more autonomous manufacturing environments.

Technology readiness

Quantum sensing is one of the most advanced areas of applied quantum technology. Devices using quantum principles, such as NV centres in diamonds or atom interferometry, are already being tested and deployed in industrial labs and pilot facilities.

Early commercial systems are being evaluated for **process monitoring, materials analysis**, and **field-based sensing**, with strong momentum toward ruggedised, scalable solutions.

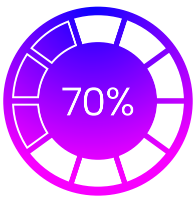
Over the coming five years, as form factors shrink and robustness improves, we can expect to see wider integration of quantum sensors into real-time control systems across the chemicals and materials value chain.

Leading players and experiments

Qnami and Z**urich Instruments** are developing quantum sensors for ultra-sensitive magnetic field detection and nanoscale materials analysis.

The Fraunhofer Institute and SBQuantum are leading applied research into industrial quantum sensing, with use cases in quality control, material testing, and environmental monitoring.

BASF and **Solvay** are piloting the use of quantum sensors in chemical processing environments to improve quality assurance and process safety.



Maturity barometer

Working in industrial pilots; scaling remains.

Chemicals & Materials

Conclusion to the Chemicals & Materials series

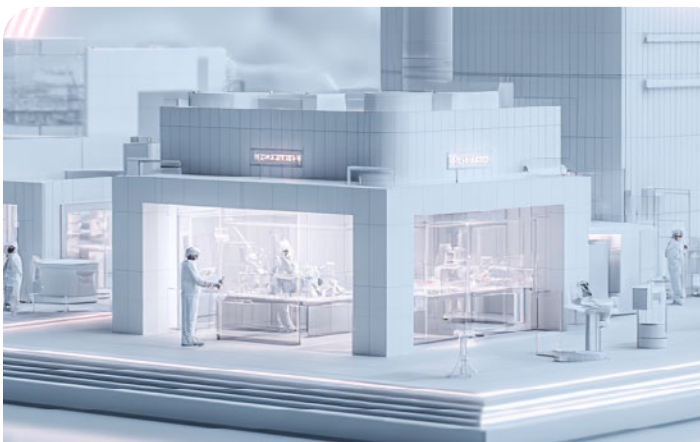
The future of materials won't be shaped by chance. It will be designed with quantum precision. From discovering entirely new compounds to fine-tuning reactions and monitoring every detail of production, quantum technologies are reimagining how we create, transform, and control the substances that power our world.

Imagine catalysts engineered atom by atom, supply chains that adapt in real-time, and factories where materials are monitored at the quantum level for safety, purity, and performance. This isn't distant speculation, it's a transformation already in motion, with early pilots proving both the potential and the business case.

Belgium, with its world-class research hubs, industry leaders, and collaborative innovation ecosystem, is positioned to lead this materials revolution. By connecting technology, business, research, and society, **Quantum Circle** is ensuring that the quantum shift in chemicals and materials is not only cutting-edge, but also collaborative, sustainable, and globally competitive.

The question is no longer if quantum will impact your value chain, but **when**, and **how prepared you'll be** to lead the change.

Discover more use cases on **quantumcircle.eu**



Energy
& Utilities

9
Smarter grids: how quantum computing is powering the future of energy

The energy transition is accelerating, but our power grids are struggling to keep up. As more renewables come online, grid management grows exponentially more complex. Today's systems must balance supply and demand in real-time, adapt to weather-driven fluctuations, and make decisions across millions of endpoints. Classical computing alone can't keep pace. Quantum computing offers a new approach, one that could unlock faster, smarter, and more sustainable grid operations.

In this article, we explore how quantum algorithms are being applied to optimise grid performance and why this matters for energy providers, utilities, and the planet.

Case: **Energy grid optimisation with quantum computing**

Electric grids involve countless variables: energy demand, supply sources, weather forecasts, grid topology, market prices, and more. Classical algorithms often oversimplify the problem or run into bottlenecks. Quantum algorithms, on the other hand, can evaluate a vast number of configurations simultaneously, finding more optimal solutions for load balancing, energy dispatch, and network reliability.

Business value

- **Improved grid reliability and resilience:** Quantum-optimised systems can anticipate disruptions, rebalance loads faster, and reduce the risk of blackouts.
- **Enhanced integration of renewable energy sources:** More accurate forecasting and dynamic optimisation help grids accommodate the variability of solar and wind power.
- **Reduced operational costs:** Better resource allocation and reduced inefficiencies lower the cost of managing energy distribution.
- **Real-time decision-making:** Quantum-enhanced models enable near-instant adjustments to changing grid conditions, improving responsiveness.

Technology readiness

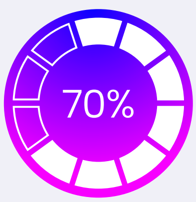
Quantum grid optimisation is transitioning from lab to pilot stage. Hybrid quantum-classical approaches are already being tested in real-world scenarios, where classical systems handle real-time data and quantum solvers optimise the most complex sub-problems. While full-scale deployment is still years away, these early trials show measurable improvements in performance, setting the stage for broader adoption.

Leading players and experiments

EDF (France) is running quantum pilots focused on grid stability and load forecasting, in collaboration with quantum computing startups.

IBM and **D-Wave** provide quantum computing platforms that utilities use to simulate energy dispatch, congestion management, and demand forecasting problems.

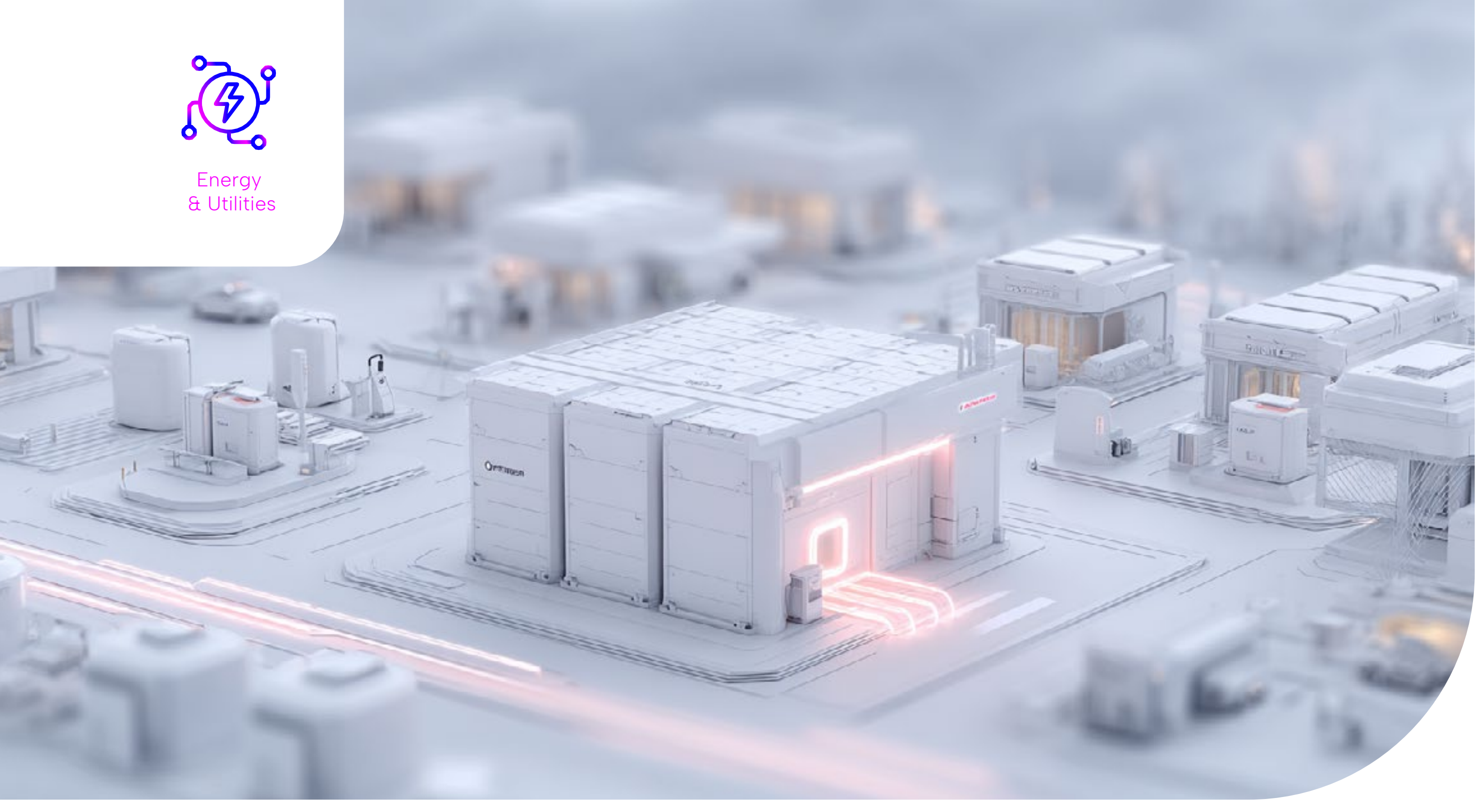
National Grid (UK) is exploring quantum computing's potential to strengthen the UK's electricity system, with emphasis on resilience and integration of renewables.



Maturity barometer

Pilots show measurable benefits in grid stability and renewable integration.

Energy
& Utilities



10
From atoms to energy: how quantum simulation is unlocking better storage materials

As we electrify more of our economy, the demand for advanced energy storage is surging. But today's materials are nearing their limits. To create batteries and fuel cells that are safer, more efficient, and more sustainable, we need to rethink how materials are discovered and designed. That's where quantum simulation comes in.

Quantum computers can model complex atomic interactions with extreme precision, something classical computers often fail to do at scale. This capability is opening new frontiers in material science, enabling faster breakthroughs in energy storage.

In this article, we look at how quantum tools are transforming battery innovation and what this means for energy, industry, and climate goals.

Case: **Material innovation with quantum simulation for batteries and fuel cells**

Battery and fuel cell performance depends on properties like ion mobility, chemical stability, and energy density, all determined at the atomic level. Quantum simulation makes it possible to accurately model these properties, identify promising materials, and accelerate their development without extensive physical testing.

Business value

- **Accelerated development of sustainable energy storage:** Quantum simulation enables faster discovery of high-performance materials, such as solid-state electrolytes and high-capacity anodes.
- **Reduced R&D costs:** Accurate modeling reduces reliance on costly trial-and-error experimentation in the lab.
- **Competitive advantage:** Proprietary materials developed through quantum methods offer a strategic edge in the energy market.
- **Support for electrification and decarbonization:** Better batteries and fuel cells enable cleaner transportation, grid storage, and industrial energy use.

Technology readiness

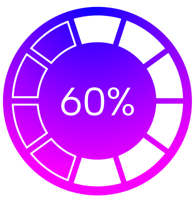
Quantum simulation is already being used in research and early-stage pilot projects. While today's quantum computers are limited, hybrid quantum-classical approaches are making it possible to model materials with useful accuracy. Many energy and chemical companies are now integrating quantum tools into their R&D pipelines. Broader deployment will depend on further advances in quantum hardware and software over the next five to ten years.

Leading players and experiments

BASF and **Volkswagen** are working with quantum computing companies to discover next-generation battery materials, including solid-state components.

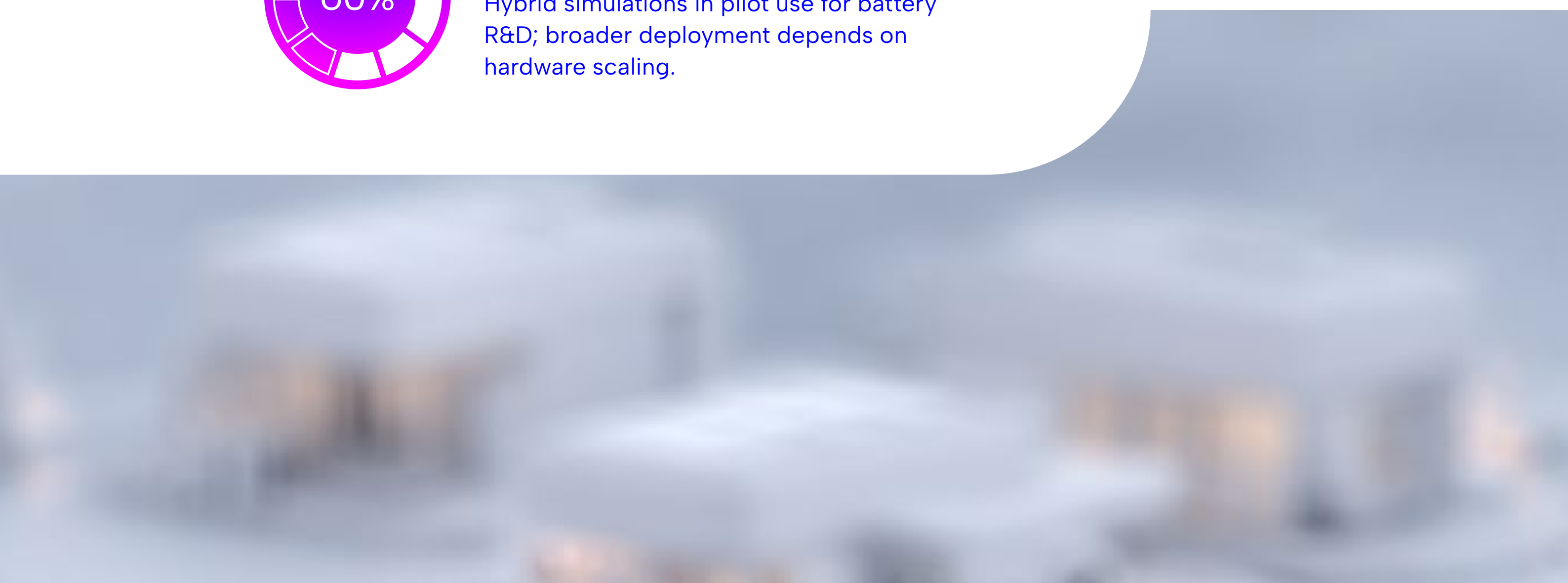
IBM and **Microsoft** offer cloud-based quantum platforms that allow researchers to run advanced material simulations relevant to energy storage.

TotalEnergies is exploring the use of quantum chemistry to improve the performance and sustainability of energy technologies, including fuel cells.



Maturity barometer

Hybrid simulations in pilot use for battery R&D; broader deployment depends on hardware scaling.



Energy
& Utilities

11
Smarter uptime: how quantum machine learning is powering predictive maintenance

In the energy sector, equipment failure isn't just inconvenient… it can be catastrophic! From turbines and transformers to pipelines and substations, critical infrastructure must run reliably. Predictive maintenance aims to anticipate failures before they happen, using data from sensors and operational logs. But the complexity of this data often exceeds what classical models can fully interpret.

Quantum machine learning (QML) is changing that. By analysing high-dimensional datasets with greater accuracy, QML can detect subtle anomalies and predict failures earlier and more precisely than traditional methods.

In this article, we explore how quantum-enhanced maintenance strategies are shaping the future of operational reliability.

Case: **Predictive maintenance with quantum machine learning**

Industrial energy systems produce vast amounts of sensor data. Classical algorithms struggle to detect complex patterns hidden within this data, especially when interactions span multiple systems or conditions. QML models can process and learn from this high-dimensional input more effectively, unlocking new insights into asset health and failure prediction.

Business value

- **Reduced downtime and maintenance costs:** Better failure prediction allows for proactive servicing, avoiding costly breakdowns and service interruptions.
- **Increased asset lifespan and reliability:** Identifying early signs of wear or malfunction extends equipment life and optimises replacement timing.
- **Improved safety and compliance:** Predictive insights reduce the risk of hazardous failures, supporting safety regulations and environmental standards.
- **Optimised maintenance scheduling:** Smart scheduling ensures maintenance crews and resources are deployed efficiently, minimising disruptions.

Energy
& Utilities

Technology readiness

Quantum machine learning is currently in the experimental phase, with early pilots underway. Energy companies are testing QML models using real-world sensor data in controlled environments.

These hybrid systems use classical infrastructure to collect and preprocess data, while quantum models handle pattern recognition and forecasting. Wider adoption will follow improvements in QML algorithms, quantum hardware, and integration into industrial software ecosystems.

Leading players and experiments

Siemens Energy and **GE** are exploring how quantum machine learning can enhance asset monitoring and predictive diagnostics in energy systems.

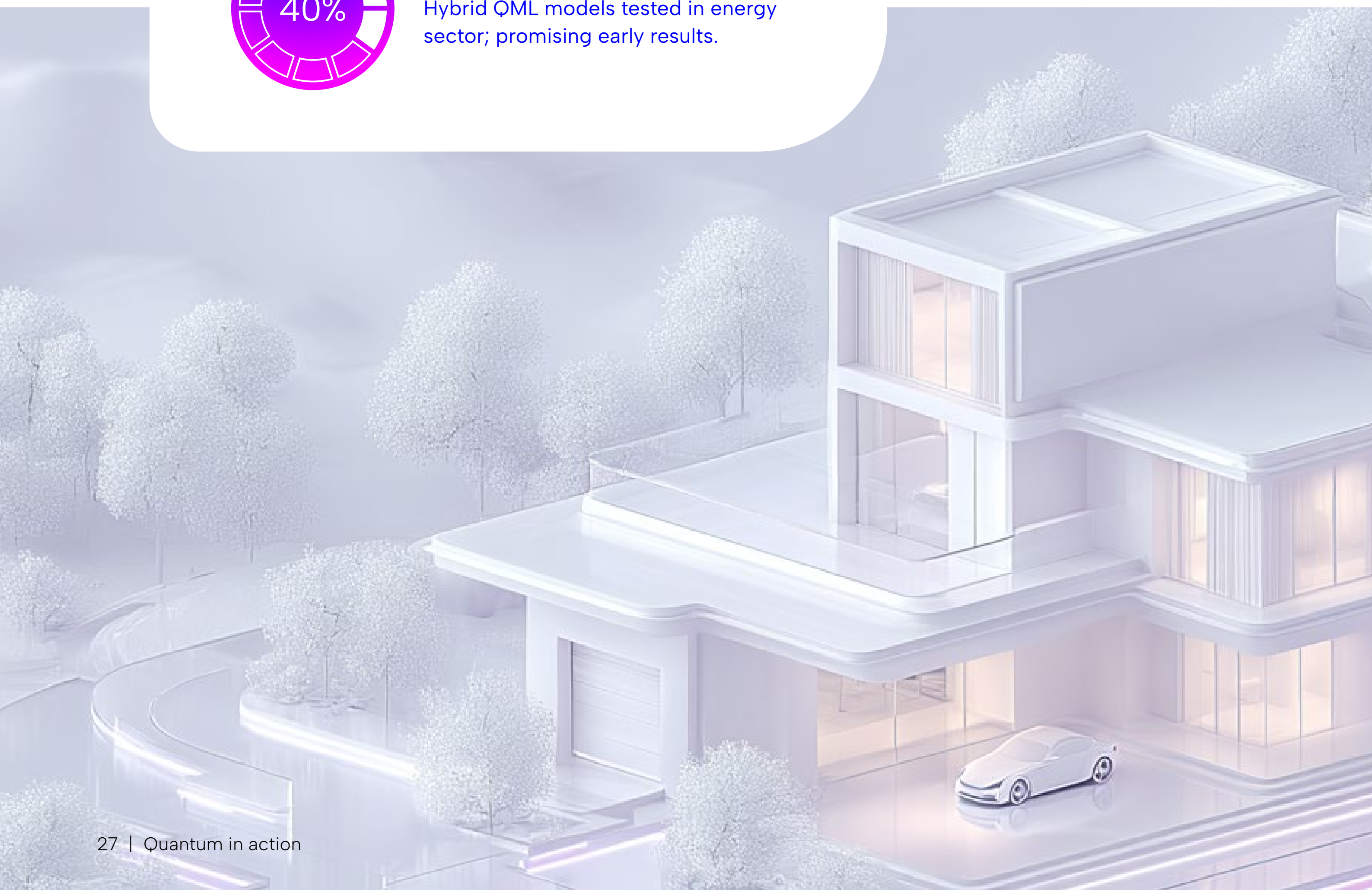
Zapata Computing and **Rigetti** provide QML platforms and tools tailored to industrial use cases, including predictive maintenance.

E.ON and **Enel** are engaging in quantum innovation programs that evaluate predictive maintenance as a key application for infrastructure resilience.

40%

Maturity barometer

Hybrid QML models tested in energy sector; promising early results.



Energy
& Utilities

12
Seeing deeper: how quantum sensing is redefining energy exploration

Finding new energy resources is a high-stakes challenge. Traditional exploration techniques often rely on indirect data and invasive drilling, making them costly, time-consuming, and environmentally disruptive. Quantum sensing offers a radical new approach.

By measuring magnetic, gravitational, and electric fields with unprecedented precision, quantum sensors can detect subsurface structures and anomalies that reveal the presence of oil, gas, geothermal reservoirs, and other critical resources. This leap in sensitivity enables more accurate exploration while reducing environmental impact.

In this article, we examine how quantum sensors are advancing the frontier of energy discovery.

Case: **Subsurface exploration with quantum sensing**

Quantum sensors can detect minute variations in physical fields, providing detailed insights into underground formations. Unlike traditional geophysical methods, quantum sensing can identify features invisible to classical tools, allowing for more targeted drilling and resource mapping.

Business value

- **Improved accuracy in locating energy resources:** Quantum-enhanced measurements reduce uncertainty, increasing the success rate of exploration projects.
- **Lower exploration costs and environmental impact:** Better data leads to fewer exploratory wells, minimising land use, emissions, and ecological disturbance.
- **Enhanced decision-making for drilling and site selection:** High-resolution sensing enables more strategic and informed investments in resource development.
- **Competitive edge in resource discovery:** Companies that leverage quantum sensing can move faster, spend less, and explore more sustainably.

Technology readiness

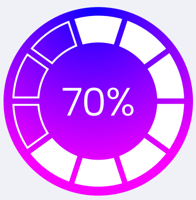
Quantum sensors are moving from lab prototypes to early commercial deployment. Field trials in geophysics and energy exploration are already demonstrating their potential, especially in areas where classical sensing struggles, such as beneath urban environments or in geologically complex regions. Scaling up requires ruggedizing the technology and integrating it with existing exploration workflows, but momentum is growing rapidly.

Leading players and experiments

BP and **Shell** are investigating quantum sensing technologies to improve the precision and efficiency of their exploration operations.

Qnami and **SBQuantum** are developing commercial-grade quantum sensors based on nitrogen-vacancy (NV) centers and other quantum effects for industrial applications.

Fraunhofer Institute is leading applied research projects in Europe focused on integrating quantum sensors into geophysical exploration systems.



Maturity barometer

Proven field trials; integration is pending.

Energy & Utilities

Conclusion to the Energy & Utilities series

The future of energy will be shaped by bold new technologies that rethink how we generate, distribute, and consume power. Quantum is emerging as a catalyst across every layer of the energy system. From **optimising grid operations** to **accelerating material discovery** for better batteries… from anticipating equipment failures to seeing beneath the surface with unmatched sensing precision, quantum technologies are unlocking real-world solutions to energy's biggest challenges. This isn't a distant vision. Research pilots are underway. Industry leaders are investing. The quantum shift in energy has begun.

Belgium, with its robust research ecosystem, industrial base, and commitment to sustainability, is well-positioned to lead. At **Quantum Circle**, we're building the connections between business, research, technology, society, and ecosystems to make quantum work for energy and for the planet.

Discover more use cases on **quantumcircle.eu**

Financial services

13 Sharper strategies: how quantum computing is transforming portfolio optimisation

Portfolio management is a delicate balancing act. With thousands of assets, shifting market conditions, and tight regulatory constraints, finding the optimal investment mix is a problem of overwhelming complexity. Traditional algorithms struggle to deliver real-time insights at scale.

Quantum computing changes the game. By evaluating vast solution spaces in parallel, quantum algorithms can tackle optimisation problems that classical systems can't. This opens the door to faster rebalancing, more agile risk management, and stronger portfolio performance.

In this article, we explore how quantum computing is redefining financial optimisation, and why the institutions preparing now are poised to lead.

Case: **Portfolio optimisation with quantum computing**

Financial institutions must constantly assess how to allocate assets across portfolios while balancing risk, return, liquidity, and regulatory requirements. The number of possible combinations grows exponentially as portfolios scale. Quantum algorithms like QAOA (Quantum Approximate Optimisation Algorithm) can evaluate these possibilities far more efficiently, helping institutions model scenarios and rebalance in near real-time.

Financial services

Business value

- **Competitive edge:** Faster, more accurate optimisation can lead to better performance and reduced exposure.
- **Cost reduction:** Streamlined modeling and automation reduce the cost of portfolio management.
- **Client trust:** Better results and increased transparency can attract institutional clients and boost confidence.
- **Strategic agility:** Firms can respond faster to market shocks, regulatory changes, and client needs.

Technology readiness

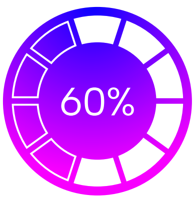
Quantum portfolio optimisation is in the pilot phase. Financial institutions are testing hybrid quantum-classical models to solve subsets of larger optimisation problems. While quantum advantage hasn't yet been achieved in production environments, early results are promising. As hardware improves and algorithms evolve, portfolio optimisation is expected to be one of the earliest value-generating applications in financial services.

Leading players and experiments

Goldman Sachs, **JP Morgan Chase**, and **HSBC** are piloting quantum portfolio strategies in collaboration with IBM, D-Wave, and QC Ware.

Fidelity Investments is partnering with quantum providers to explore optimisation use cases that improve asset management efficiency.

Multiverse Computing specialises in quantum solutions for finance and is working with banks and asset managers to test real-world portfolio applications.



Maturity barometer

Pilots with hybrid models underway at major financial institutions.

Financial services

14 Quantum vs. fraud: how quantum machine learning is exposing hidden threats

Fraud in financial services is evolving fast and so must the tools used to fight it. Today's systems rely on classical machine learning to detect anomalies in massive streams of transaction data. But as fraud patterns become more complex, these tools are hitting their limits.

Quantum machine learning (QML) offers a powerful new weapon. By analysing high-dimensional data with greater nuance, QML can identify subtle correlations and irregularities that classical systems overlook. This could radically improve real-time fraud detection across banking, payments, insurance, and beyond.

In this article, we explore how quantum models are being tested for fraud detection and what this means for financial institutions looking to stay one step ahead.

Case: **Fraud detection with quantum machine learning**

Detecting fraud means recognizing small signals in massive noise. Quantum ML techniques, such as quantum support vector machines and quantum neural networks, can process multidimensional data more efficiently than classical methods, increasing the chances of catching fraud early without overwhelming systems with false positives.

Financial services

Business value

- **Reduced financial losses:** Early detection prevents fraud from spreading, saving millions in damage and recovery costs.
- **Regulatory compliance:** Stronger fraud detection helps institutions meet evolving AML and anti-fraud standards.
- **Operational efficiency:** Quantum models can reduce the manual workload of compliance teams by improving automated detection.
- **Improved customer experience:** Fewer false positives mean legitimate users face less friction during transactions.

Technology readiness

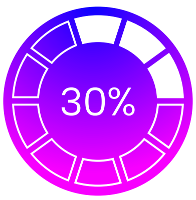
Quantum machine learning for fraud detection is still in the experimental phase. Financial firms and quantum startups are piloting small-scale models using real-world datasets. Hybrid setups combine classical pre-processing with quantum classifiers to analyse transaction data in real-time. While QML hasn't replaced classical systems yet, early results are promising—particularly in use cases with complex, noisy datasets where traditional models struggle.

Leading players and experiments

IBM, **Google**, and **Rigetti** are advancing QML algorithms and cloud-based platforms for testing fraud detection scenarios.

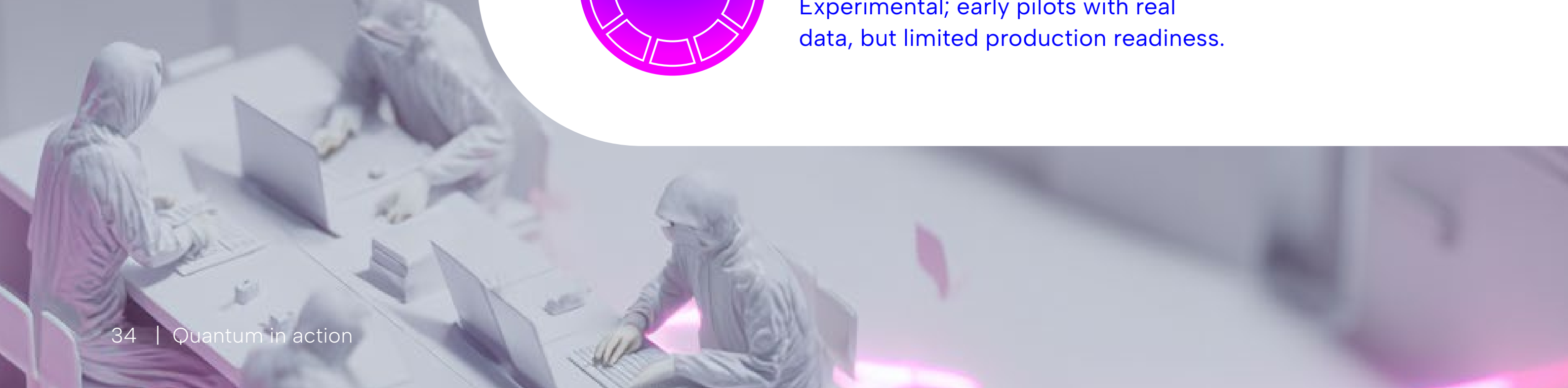
Mastercard and **BBVA** are exploring how quantum tools can strengthen their fraud prevention and anti-money laundering strategies.

SandboxAQ is developing enterprise-ready quantum and AI solutions that include fraud detection components tailored for financial services.



Maturity barometer

Experimental; early pilots with real data, but limited production readiness.



Financial services

15
Resilience by design: how quantum computing is powering better risk modeling

From market shocks to credit events, financial institutions face complex, interdependent risks every day. Modeling these scenarios requires massive computational power, especially when dealing with derivatives pricing, portfolio exposure, and systemic contagion. Classical systems often struggle to keep up.

Quantum computing offers a new toolkit. By simulating complex, multi-factor systems with greater speed and depth, quantum tools can enhance how institutions understand and manage risk. Monte Carlo simulations, scenario analysis, and stress testing stand to benefit greatly from quantum acceleration.

In this article, we look at how quantum computing is reshaping risk modeling and helping financial firms build resilience from the inside out.

Case: **Financial risk modeling with quantum computing**

Risk models must account for countless variables across time, assets, and interlinked markets. Quantum algorithms can process these variables in parallel, accelerating simulations and revealing insights that are computationally out of reach for classical systems, especially in high-stakes areas like options pricing, systemic risk modeling, and capital adequacy forecasting.

Business value

- **Improved resilience:** Stronger, more accurate models help firms anticipate and mitigate cascading risks.
- **Regulatory compliance:** Quantum-enhanced simulations support stress testing and capital adequacy requirements.
- **Faster insights:** Rapid scenario modeling empowers decision-makers with real-time responses to volatile markets.
- **Cost savings:** More efficient computation reduces the time and resources needed for large-scale simulations.

Technology readiness

Quantum risk modeling is currently in the early pilot stage. Financial institutions are testing hybrid quantum-classical models that simulate parts of their risk workflows, especially where high-dimensional modeling is needed. Full-scale adoption will depend on hardware maturity and continued algorithm development, but early signs indicate a significant edge for first movers.

Leading players and experiments

Barclays, **BBVA**, and **Citi** are experimenting with quantum-enhanced risk models to support regulatory and operational decision-making.

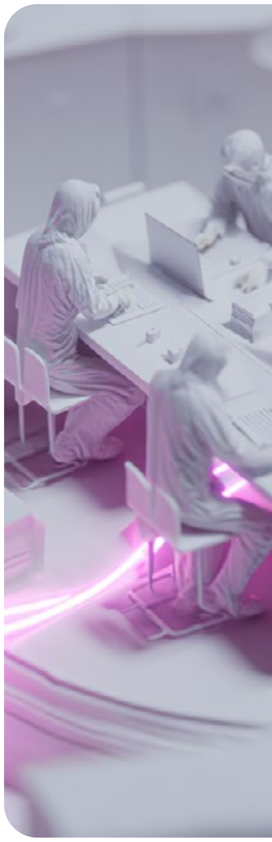
IBM, **D-Wave**, and **Multiverse Computing** offer platforms and quantum financial toolkits that help institutions model complex risk scenarios.

European banking consortia are supporting cross-border research on quantum applications for financial resilience and regulatory reporting.

Maturity barometer

Models remain experimental; not production-ready.

Conclusion to the Financial services series



From optimising portfolios to securing communications, detecting fraud to modeling risk, quantum technologies are redefining the foundations of financial services. Each application brings us closer to a future where finance is not only faster and more efficient, but also safer, more transparent, and more resilient.

This five-part series has highlighted the transformative potential of:

- **Quantum computing** for optimisation, simulation, and reporting
- **Quantum machine learning** for fraud detection and anomaly recognition
- **Quantum-safe cryptography** for securing transactions and data

These tools are being tested, piloted, and prepared for integration into the financial systems of tomorrow.

Belgium, with its strong research base and growing innovation ecosystem, is ready to play a leading role. At **Quantum Circle**, we connect financial institutions, researchers, policymakers, and technologists to ensure the quantum future is collaborative, secure, and inclusive.

Discover more use cases on **quantumcircle.eu**

Government & Defence

16 The codebreaking frontier: how quantum computing could reshape cryptanalysis

Encryption is the quiet infrastructure of modern statecraft. It protects diplomatic cables, intelligence exchanges, military communications, critical infrastructure systems, and the digital services citizens rely on every day.

But that protection is not permanent. The same mathematical foundations that make today's public-key cryptography strong can, in time, become its weakness, because quantum computing changes what is computationally feasible.

For intelligence and defence agencies it's a strategic one. Whoever gains quantum-enabled cryptanalytic capability first could decrypt adversarial communications, expose hidden networks, and extract insights from data that would otherwise remain sealed for decades.

That's why governments are preparing now, not only to defend against future quantum attacks, but to understand the offensive implications and the shifting balance of power that comes with them.

Case: **Cryptanalysis and codebreaking with quantum computing**

Many of today's most widely used cryptographic protocols depend on problems that are extremely hard for classical computers to solve at scale, such as integer factorisation (used by RSA) and the discrete logarithm problem (used by ECC).

A sufficiently capable, fault-tolerant quantum computer could solve these problems far more efficiently, making it possible to break RSA and ECC-based protections that secure:

- encrypted state and military communications
- VPNs, secure web traffic, and authentication systems
- key exchange protocols underpinning digital infrastructure
- stored encrypted archives (including sensitive historical data)

This creates a dual risk that governments must take seriously:

- "Harvest now, decrypt later": adversaries can collect encrypted traffic today and decrypt it in the future once quantum capability matures.
- Cryptographic shock: if quantum codebreaking becomes practical faster than expected, legacy systems could become unsafe with limited time to migrate.

In this context, quantum cryptanalysis is a forcing function: it accelerates the need to modernise cryptography, upgrade key management, and adopt quantum-resilient security architectures across the public sector.

Business value

- **Strategic advantage in intelligence operations:** Quantum-enabled cryptanalysis could unlock high-value adversarial communications and accelerate insight extraction in time-critical missions.
- **Clearer visibility into national cryptographic vulnerabilities:** Understanding what quantum attacks could break helps governments prioritise upgrades across infrastructure, procurement, and classified systems.
- **Faster development of quantum-resilient protocols:** Preparing for the threat drives the adoption of post-quantum cryptography, crypto-agility, and security-by-design in new government services.
- **Stronger national cybersecurity posture:** Early migration reduces exposure to long-term data compromise and supports resilience across defence, diplomacy, energy, mobility, and citizen-facing systems.

Technology readiness

Quantum cryptanalysis that meaningfully threatens RSA and ECC at scale requires fault-tolerant quantum computers, hardware with enough stable qubits and robust error correction to run large, complex algorithms reliably. That level of capability is still in the research and experimental phase.

But the strategic reality is that migration timelines are long. Government systems are complex, procurement cycles are multi-year, and cryptography is deeply embedded. Waiting for a "quantum breakthrough headline" is the wrong trigger. The practical trigger is: how long it takes to upgrade everything that matters.

Near-term action focuses on:

- crypto-agility (systems that can swap algorithms without redesign)
- inventorying where RSA/ECC are used across agencies and suppliers
- piloting and rolling out post-quantum cryptography
- strengthening key management, identity, and long-term data protection policies

Leading players and experiments

NSA and **GCHQ** are researching quantum-era cryptographic risks and the implications for intelligence and national security.

IBM and **Google** continue to advance quantum processors and tooling that support experiments relevant to cryptographic workloads.

SandboxAQ is exploring quantum security applications, including approaches that help organisations transition to quantum-resilient systems.

Maturity barometer

PQC standards finalised; QKD in early commercial deployment.

Government & Defence

17 **Beyond GPS:** how quantum sensing enables navigation in contested environments

GPS has become the invisible foundation of modern operations, from defence and aviation to emergency response and critical infrastructure. But that dependence creates a strategic vulnerability. In contested airspace, underwater missions, underground operations, or during jamming and spoofing events, GPS signals can be degraded or unavailable entirely.

For governments and defence agencies, losing navigation is not an inconvenience. It's a mission risk. The next leap in resilience is the ability to navigate with confidence without relying on satellites.

Quantum sensing offers that capability. By measuring inertial and gravitational forces with extreme precision, quantum inertial navigation systems can track position and movement even when GPS is denied — enabling new levels of operational autonomy and security.

Case: **Navigation without GPS using quantum sensing**

Traditional inertial navigation systems drift over time, requiring periodic corrections, often from GPS. Quantum inertial sensors aim to reduce that drift dramatically by leveraging quantum effects to measure acceleration and rotation with far higher precision.

This enables navigation in environments where satellite signals are unreliable or compromised, including:

- **Underwater operations** (submarines and underwater drones)
- **Underground or urban canyon environments** (tunnels, dense cities)
- **Contested airspace** where GPS is jammed or spoofed
- **Disaster response scenarios** where infrastructure is damaged

The result is a navigation stack designed for continuity, not convenience, maintaining trusted positioning when external signals can't be trusted.

Government
& Defence

Business value

- **Reliable navigation in GPS-denied or jammed environments:** Maintain positioning and timing when satellites are unavailable or compromised.
- **Enhanced operational capabilities:** Strengthen mission execution for defence, border security, and emergency services in challenging conditions.
- **Reduced vulnerability to satellite disruptions:** Lower dependence on a single point of failure in the navigation chain.
- **Strategic autonomy:** Build sovereign capability in next-generation navigation technologies, aligned with security and resilience goals.

Technology readiness

Quantum inertial sensors are currently in prototype and field trial stages. Defence agencies are investing heavily in R&D to prove stability, ruggedisation, and performance under real operational conditions, where vibration, temperature shifts, and movement are constant.

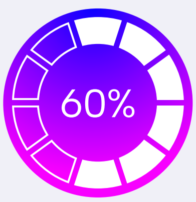
Near-term adoption is most likely in high-value scenarios where GPS denial is common and the cost of failure is high. Wider deployment will depend on miniaturisation, integration into existing platforms, and sustained performance over long periods without recalibration.

Leading players and experiments

The **UK Ministry of Defence** has supported quantum navigation trials focused on resilient positioning in GPS-denied environments.

Honeywell and **Northrop Grumman** are developing advanced inertial and quantum-enhanced navigation technologies for defence and aerospace applications.

The **Fraunhofer Institute** is advancing applied research in quantum positioning and navigation systems, supporting pathways from lab to field integration.



Maturity barometer

Quantum inertial sensors are in prototype phase; promising for GPS-denied environments but not yet commercially deployed.

Government
& Defence

18 Decision advantage: how quantum machine learning could transform threat detection modeling

Modern security depends on seeing patterns before they become crises. But today's threat landscape produces overwhelming volumes of data: network telemetry, satellite imagery, signals intelligence, open-source information, sensor feeds, and operational reports, often fragmented, noisy, and time-sensitive.

Classical analytics and AI are already essential, but the scale and complexity of these datasets is growing faster than the ability to interpret them. The result is a familiar challenge for defence and government: critical signals can be missed, correlations remain hidden, and response time suffers.

Quantum-enhanced machine learning (QML) aims to shift that balance. By combining quantum computing with advanced learning methods, QML may improve pattern discovery in complex datasets — supporting earlier detection of cyber intrusions, emerging security threats, and battlefield anomalies.

Case: **Threat detection with quantum machine learning**

Threat detection is, at its core, a pattern problem: identifying weak signals amid noise, detecting anomalies across many variables, and connecting events that appear unrelated. Quantum-enhanced ML approaches are being explored to support:

- Cyber intrusion detection across high-dimensional network data
- Anomaly detection in surveillance and reconnaissance feeds
- Correlation discovery across disparate intelligence sources
- Decision support for real-time situational awareness in complex operations

The near-term reality is hybrid: classical systems manage data pipelines and model training, while quantum routines may help with specific optimisation or feature-mapping steps — especially where many constraints and variables collide.

Business value

- **Improved national security through early detection:** Spot emerging threats sooner, before they escalate into major incidents.
- **Enhanced situational awareness and decision-making:** Support analysts and commanders with faster, clearer signal extraction across diverse sources.
- **Reduced response time:** Accelerate triage and prioritisation during critical events, improving operational tempo.
- **Support for autonomous systems:** Strengthen surveillance, reconnaissance, and autonomous platforms with improved anomaly and pattern detection.

Technology readiness

QML for threat detection is in the experimental phase. Models are being tested in defence simulations and cybersecurity environments, but consistent real-world advantage over state-of-the-art classical AI is not yet proven across all tasks.

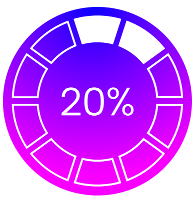
Progress will depend on maturing quantum hardware, improved error mitigation, and practical toolchains that integrate with existing defence-grade systems. In the meantime, the most valuable work is happening now: benchmarking, piloting constrained sub-problems, building quantum-ready data architectures, and developing internal capability so agencies can scale quickly when the technology reaches operational maturity.

Leading players and experiments

DARPA and **NATO** have funded research into quantum approaches relevant to defence analytics and security applications, including early threat detection and decision support.

Platform providers such as IBM and Rigetti, alongside software players like Zapata Computing, provide quantum ML tooling used for experimentation and pilots.

Defence primes including **Lockheed Martin** and **Raytheon** are exploring quantum-enhanced analytics to strengthen sensing, surveillance, and security decision-making.



Maturity barometer

Conceptual threat; drives urgency for PQC adoption and crypto-agility.

Government
& Defence

Conclusion to the Government & Defence series

Quantum is reshaping government and defence along two strategic axes: resilience and advantage. Quantum-safe communications protect what must remain secure. Quantum navigation reduces dependence on vulnerable signals. Quantum machine learning aims to accelerate sense-making when speed and complexity define the operational environment.

Belgium and Europe have a clear opportunity here: to build sovereign capability, align innovation with public values, and ensure quantum technologies strengthen security while supporting trust. That takes ecosystem thinking, connecting policy, research, industry, and society, so that quantum moves from experimentation to real-world impact responsibly.

Discover more use cases on **quantumcircle.eu**

Healthcare
& Life Sciences

19
Faster cures, fewer failures: how quantum simulation is accelerating drug discovery

Bringing a new drug to market can take over a decade and billions of euros, and even then, most candidates fail before reaching patients. One of the biggest challenges lies in predicting how molecules behave at the atomic level, a task that quickly overwhelms classical computers as molecular complexity increases.

Quantum simulation offers a breakthrough. By modelling molecular interactions directly using the laws of quantum mechanics, quantum computers promise faster, more accurate insights into which compounds are likely to be safe, effective, or toxic, long before clinical trials begin.

In this blog, we explore how quantum simulation is helping researchers accelerate drug discovery, cut costs, and unlock therapies for conditions once considered untreatable.

Case: **Drug discovery and molecular modelling with quantum simulation**

At the heart of drug discovery is the need to understand how molecules, drug candidates, proteins and enzymes, interact with each other. Small changes at the quantum level can determine whether a compound becomes a life-saving therapy or a failed trial.

Classical supercomputers are powerful, but they rely on approximations to simulate large molecules and complex reactions. As the size and complexity of a molecular system grows, so does the computational cost… exponentially.

Quantum simulation changes the game. By encoding quantum properties directly into qubits, quantum computers can model the behaviour of atoms, bonds, and reactions with unprecedented fidelity. This opens the door to:

- Predicting molecular binding and toxicity profiles
- Modelling enzyme-ligand interactions in detail
- Screening vast libraries of compounds more efficiently
- Designing drugs for rare or poorly understood diseases

Rather than replacing classical methods, quantum tools are being integrated into hybrid workflows, combining the best of both worlds to speed up the early phases of R&D.

Business value

- **Accelerated R&D timelines:** Quantum simulation reduces the time it takes to identify viable drug candidates — from years to months in some cases.
- **Cost efficiency through digital testing:** By simulating molecule behaviour before physical testing, companies can reduce expensive lab work and failed experiments.
- **Competitive advantage through innovation:** Early access to quantum-powered platforms gives pharmaceutical leaders a head start in developing breakthrough therapies.
- **Expanded innovation pipeline:** Quantum tools enable researchers to explore novel compounds, rare diseases, and edge cases that are often excluded due to complexity

Technology readiness

Quantum simulation is still in the early research and pilot phase, with most industrial applications focused on small molecules and reaction pathways. While classical high-performance computing (HPC) remains dominant for large-scale simulations, hybrid quantum-classical workflows are now being tested in pharmaceutical labs.

Leading pharma companies are partnering with quantum hardware providers and software startups to experiment with quantum chemistry tools, refine algorithms, and prepare for future scaling.

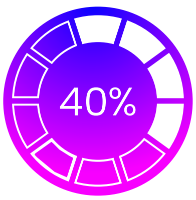
As quantum hardware advances, the complexity of molecules that can be accurately simulated will increase, bringing the promise of quantum drug discovery closer to reality.

Leading players and experiments

Roche, **Pfizer**, and **Boehringer Ingelheim** are actively working with quantum providers such as IBM, Google, and QC Ware to integrate quantum simulation into early-phase drug research.

AstraZeneca and **Merck** are exploring quantum tools for structure-based drug design and molecular binding simulations.

Software innovators like **Cambridge Quantum** and **Zapata Computing** are developing quantum algorithms tailored to pharmaceutical needs, from molecular docking to toxicity prediction.



Maturity barometer

Small-molecule
Proof-of-Concepts only

20
Smarter insights, faster breakthroughs: how quantum machine learning is reshaping genomics

A single human genome contains roughly 3 billion base pairs. Whole genome sequencing (WGS), used to 'read' the DNA, generates hundreds of gigabytes per patient. As such, genomic analysis faces several challenges. Not only in the amount of data, which requires storage, infrastructure and processing power, but also in the interpretation complexity.

Quantum machine learning (QML) combines quantum computing principles with learning algorithms and therefore brings unparalleled computational power that can fundamentally transform how genomic data is analysed.

Case: **Genomic data analysis with quantum machine learning**

Genomic analysis is becoming increasingly important in healthcare to identify genetic markers, diagnose rare diseases, develop individualised therapies, predict disease patterns or conditions, and support cancer research.

Genomic data isn't just large; it's high-dimensional. To understand the cause of a specific disease, the interactions between 10 different genes need to be mapped. This involves exponential combinations. Classical algorithms use linear or sequential processing and struggle to classify complex genetic patterns.

Quantum computers use superposition and entanglement, allowing them to process these combinations simultaneously rather than one by one. They can compare a patient's DNA to a reference in a fraction of the time needed by classical systems. As such, quantum machine learning can be more accurate and can recognise subtle patterns classical algorithms fail to see.

Quantum machine learning drives genomic analysis forward by:

- Performing more precise diagnostics
- Enhancing preventive healthcare through early risk detection
- Developing personalised medicine strategies tailored to an individual's genetic profile

Business value

- **Personalised Healthcare:** QML improves the detection of gene interactions and rare variant combinations that influence treatment response, enabling tailored treatment plans.
- **Faster Diagnostics:** Quantum algorithms process high-dimensional sequence alignments exponentially faster, reducing the time to diagnose genetic disorders from years to hours.
- **Cost Reduction:** QML optimises feature selection and compresses complex search spaces, reducing computational overhead for certain tasks.
- **Population Health:** Quantum-enhanced modelling enables the identification of emerging disease trends and genetic risk factors across entire populations in real-time.

Technology readiness

Quantum machine learning for genomics is still in the research and exploratory pilot phase. Most published work today involves small proof-of-concept studies, simulated quantum environments, hybrid quantum–classical models, and synthetic or downscaled genomic datasets.

Classical machine learning remains industry standard today, amongst other reasons, because it is reliable, well-integrated into clinical workflows and has established regulatory pathways. QML is advancing rapidly but is in the Noisy Intermediate-Scale Quantum (NISQ) era: limited in qubit count, sensitive to noise, and error prone.

Startups are increasingly partnering with regional authorities and academic institutions to create innovation 'clusters' to build manufacturing and computing facilities specifically for quantum applications. Major pharmaceutical players are investing now to develop the capabilities to use quantum methods for complex problems like mRNA folding as hardware matures.

Leading players and experiments

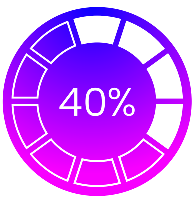
GE HealthCare is integrating multimodal genomic and pathology data into deep learning models.

IBM, through its Discovery Accelerator partnership with the Cleveland Clinic, uses its quantum hardware to optimise human genome sequencing and identify candidate drugs for repurposing in neurodegenerative diseases.

Google's Quantum AI team focuses on algorithms for today's pre-error-corrected processors to simulate molecular systems and gene expression. Much of their work remains at the proof-of-concept and academic stage.

Menten AI developed what is regarded as the first peptide designed on a quantum computer and is using a hybrid platform to create cyclic peptides for conditions like COVID-19 and cancer. Within the same area of expertise, **ProteinQure** specialises in high-accuracy simulations for protein-based drug discovery.

The **National Institutes of Health (NIH)** fund the development of quantum-optimised treatment plans and personalised medicine strategies across academic and private sectors.



Maturity barometer

Proof-of-concept studies; not yet integrated into clinical pipelines.

Healthcare
& Life Sciences

21
Seeing sooner:
how quantum sensing is sharpening medical imaging

Modern medicine depends on imaging. MRI, PET, and CT scans guide diagnosis, surgery, and treatment decisions every day. Yet many diseases, from cancers to neurological disorders, develop quietly, long before they become visible with conventional tools.

That gap is costly. Late detection limits treatment options, increases complexity, and drives healthcare spending. The next leap in care won't come from more scans; it will come from better signal: higher sensitivity, clearer resolution, and earlier insight into what's changing inside the body.

Quantum sensing offers exactly that. By using quantum effects to measure extremely small changes in magnetic or electric fields, quantum sensors can push imaging beyond today's limits, potentially revealing biological processes at the molecular or cellular level. And because some quantum sensors can operate at room temperature, they're becoming increasingly practical for real clinical environments.

Case: **Medical imaging enhancement with quantum sensing**

Quantum sensors, including nitrogen-vacancy (NV) centers in diamonds, can detect tiny magnetic signals with exceptional precision. In medical imaging, this can translate into:

- Higher sensitivity MRI (detecting weaker signals, improving contrast, reducing scan time)
- Earlier detection of subtle abnormalities associated with cancer or neurodegenerative disease
- Better monitoring of treatment response over time with more precise measurement
- New diagnostic frontiers such as imaging at molecular scale in research and specialised clinical applications

The result: imaging that moves from “confirming disease” to detecting disease earlier and tracking it more intelligently.

Business value

- **Earlier detection:** Catching disease at more treatable stages improves outcomes and reduces downstream costs.
- **Better diagnosis and monitoring:** Higher precision supports more accurate clinical decisions and therapy adjustment.
- **Operational efficiency:** Improved sensitivity can reduce repeat scans and limit the need for invasive diagnostic procedures.
- **New revenue streams:** Advanced imaging capabilities enable specialised services and research partnerships in high-value care areas.

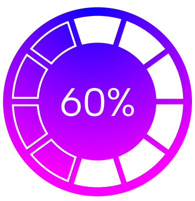
Technology readiness

Quantum-enhanced imaging is moving from research into early commercial products and clinical prototypes. Several systems and sensor technologies are being tested in controlled clinical trial settings, with adoption expected to increase as sensor costs fall and clinical integration improves.

The gating factors are familiar in healthcare innovation: regulatory approvals, device validation, workflow integration, and clinical evidence. As these pathways mature, quantum sensing is positioned to become a practical advantage first in specialised centres, then more broadly as devices scale.

Leading players and experiments

Qnami, **GE Healthcare**, **Siemens Healthineers**, **NVision Imaging**, **Magritek**, **University of Oxford**, and **Harvard Medical School**.



Maturity barometer

Technology transitioning from prototypes toward initial adoption.

22
From trial to treatment faster: how quantum computing could transform clinical trials

Clinical trials are one of the biggest bottlenecks in healthcare innovation. They're expensive, slow, and often unpredictable, with recruitment delays, complex protocols, and high failure rates even after years of R&D. For patients waiting on new therapies, every delay matters. For companies, every failed trial can mean hundreds of millions lost and years of momentum gone.

The challenge is complexity. Trials must balance safety, efficacy, diversity, and feasibility, while analysing massive, messy datasets from real-world clinical environments. Classical tools can help, but as trial designs become more adaptive and data-rich, optimisation becomes harder and slower.

Quantum computing and quantum-enhanced machine learning offer a new approach: exploring vast combinations of variables to design better trials, identify the right patient cohorts, and detect signals earlier, increasing the likelihood of success while reducing time to approval.

Case: **Clinical trial optimisation with quantum computing & ML**

Clinical trial performance depends on thousands of decisions: inclusion criteria, site selection, recruitment strategies, endpoints, dosing schedules, monitoring frequency, and analysis methods. Each decision affects cost, duration, and outcome probability — and small changes can make or break a trial.

Quantum approaches can support:

- **Trial design optimisation: i**dentifying protocols that balance statistical power, feasibility, and patient burden
- **Patient selection and stratification:** finding cohorts most likely to benefit based on clinical, genomic, and real-world data
- **Recruitment and site planning:** optimising where trials run and how quickly eligible patients can be enrolled
- **Outcome simulation and signal detection:** modelling trial scenarios to anticipate dropouts, variability, and likely efficacy signals

Most near-term implementations will be hybrid: classical computing handles data pipelines and model training, while quantum routines tackle the hardest optimisation steps, especially when many constraints and trade-offs collide.

Business value

- **Faster time-to-market:** Optimised designs and better recruitment accelerate development timelines and approvals for new treatments.
- **Cost savings:** Reducing failed trials and inefficient recruitment lowers the enormous cost of late-stage setbacks.
- **Improved efficacy and patient impact:** Better matching between patients and therapies increases the chance of meaningful clinical outcomes.
- **Regulatory advantage:** Quantum-enabled analytics can support adaptive trial designs, improved monitoring, and stronger evidence generation over time.

Technology readiness

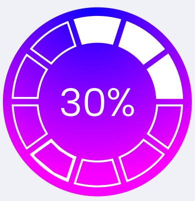
Clinical trial optimisation using quantum computing and quantum-enhanced ML is still in early-stage research and pilot testing. The main constraints today are quantum hardware scale, noise, and the effort required to integrate quantum routines into validated, regulated clinical workflows.

That said, momentum is building. Hybrid approaches are being explored to demonstrate value in constrained trial sub-problems, like cohort selection, protocol optimisation, and multi-parameter scheduling, where quantum optimisation could provide faster or better solutions as platforms mature.

As quantum computing improves over the next five to ten years, the opportunity grows: trials that are more adaptive, more efficient, and more likely to succeed, without compromising safety or scientific rigour.

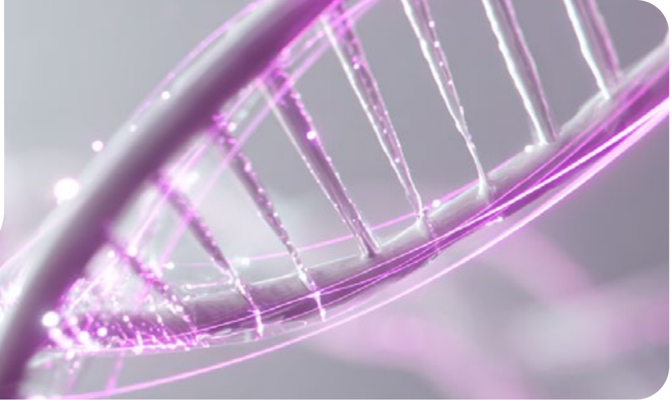
Leading players and experiments

Pfizer, **Novartis**, **Roche**, **Zapata Computing**, **Cambridge Quantum**, **FDA**, **EMA**.



Maturity barometer

Early research; no operational deployments yet.



Conclusion to the Healthcare & Life Sciences series

Quantum in healthcare isn't a single breakthrough, it's a connected shift across discovery, diagnosis, security, and delivery. Quantum simulation accelerates drug discovery. Quantum machine learning helps decode complex biology. Quantum sensing sharpens imaging and detection. Post-quantum security protects the data layer that care depends on. And clinical trial optimisation can help ensure promising therapies reach patients faster, with fewer failures along the way.

Belgium has what it takes to **lead this transformation**: strong life sciences, world-class research, and an ecosystem mindset that connects business, technology, research, society, and ecosystems. The next era of healthcare innovation will be built by those who collaborate early, turning emerging capability into real-world impact.

If you're ready to explore where quantum could strengthen your R&D or clinical roadmap, **Quantum Circle** is where Belgium's quantum community comes together to make quantum work, through use cases, partnerships, and practical pathways from pilot to adoption.

Discover more use cases on **quantumcircle.eu**

Manufacturing & Logistics

23

Stronger, smarter supply chains: how quantum computing is reshaping logistics and manufacturing

Global supply chains are under increasing pressure. Whether it's fluctuating demand, unexpected disruptions, or the sheer complexity of coordinating parts, products and people, traditional optimisation tools often struggle to keep up. In today's volatile landscape, manufacturers and logistics providers need systems that aren't just efficient, but adaptive.

Quantum computing is emerging as a powerful tool to tackle this complexity head-on. By processing vast combinations of variables in parallel, quantum algorithms can identify optimal or near-optimal solutions far faster than classical methods, even as conditions change in real-time.

In this article, we explore how quantum is helping reimagine supply chains for resilience, speed, and precision and why early adopters are already gaining a strategic edge.

Case: **Supply chain optimisation with quantum computing**

Supply chains are intricate systems with countless moving parts, from raw material sourcing to inventory levels, warehouse locations, shipping routes, and demand forecasts. The challenge lies not just in planning, but in adapting to constant change: weather events, geopolitical shifts, transport delays, or supplier shortages.

Quantum algorithms, particularly the Quantum Approximate Optimisation Algorithm (QAOA), can explore huge optimisation spaces in parallel, helping to solve problems that are either too large or too time-sensitive for classical computers.

Applications include:

- **Vehicle routing:** Finding the most efficient paths for fleet operations
- **Inventory optimisation:** Balancing stock across multiple locations to reduce costs and delays
- **Real-time re-optimisation:** Dynamically adjusting operations in response to sudden disruptions
- **Demand forecasting:** Improving the accuracy of predictions by modelling complex correlations

Most current implementations use **hybrid quantum-classical approaches**, with classical systems handling real-time data inputs and quantum solvers tackling the hardest parts of the problem.

Manufacturing & Logistics

Business value

- **Cost reduction:** Quantum optimisation reduces fuel costs, warehousing expenses, and inventory losses by fine-tuning logistics flows.
- **Increased resilience:** Organisations can respond to disruptions faster, re-routing shipments, reallocating resources, and avoiding bottlenecks.
- **Improved customer service:** More accurate demand forecasting and reliable delivery windows enhance satisfaction and retention.
- **Competitive advantage:** Quantum-enabled supply chains support more agile, efficient operations, a key differentiator in fast-moving markets.

Technology readiness

Quantum supply chain optimisation is already in the pilot and proof-of-concept stage, with encouraging results from hybrid approaches. While current hardware cannot yet solve the largest commercial problems at scale, key components, like routing and scheduling, are already being tested in live environments.

As quantum hardware improves, full-scale deployments will become more feasible, offering deeper integration with ERP, logistics and procurement systems.

For now, the most forward-thinking organisations are laying the groundwork, investing in partnerships, building internal expertise, and preparing for scalable implementation as the technology matures.

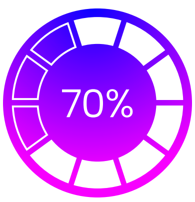
Leading players and experiments

Volkswagen, in collaboration with **D-Wave**, has run pilots on optimising taxi routing and traffic flows in urban centres using quantum algorithms.

IBM is partnering with logistics and manufacturing clients to explore supply chain use cases through its quantum cloud platform.

DHL and **Maersk** are working with quantum software startups to model distribution scenarios and improve operational responsiveness.

Multiverse Computing is developing quantum-native applications for logistics, inventory management and financial forecasting, with a focus on industrial supply chains.



Maturity barometer

Hybrid pilots show value; broader adoption awaits hardware scaling.

24
Zero-defect manufacturing: how quantum sensing is upgrading quality control

Quality control has always been the invisible engine of manufacturing performance. When it works, products ship on time, customers stay loyal, and operations scale smoothly. When it fails, defects slip through, rework piles up, and reputations take a hit.

But as manufacturing shifts toward advanced materials, tighter tolerances, and faster production cycles, classical sensors are approaching their limits. Some defects are too small, too deep, or too subtle to spot early, until they become expensive problems.

Quantum sensing changes that equation. By detecting minute changes in magnetic, electric, or gravitational fields, quantum sensors can reveal anomalies classical instruments can miss. This enables earlier detection, non-destructive testing, and real-time monitoring of production lines, helping manufacturers move from reactive inspection to predictive quality.

Case: **Quality control with quantum sensing**

Quality control depends on measuring what matters: consistently, precisely, and fast. Quantum sensors (including those based on nitrogen-vacancy (NV) centers in diamonds or superconducting circuits) offer ultra-high sensitivity that can unlock new inspection capabilities.

Use cases include:

- **Non-destructive testing (NDT):** Detecting sub-surface cracks, voids, or inconsistencies without cutting or damaging components
- **In-line process monitoring:** Tracking subtle variations in electromagnetic signals that correlate with defects as products are made
- **Quantum-enhanced imaging:** Revealing internal material anomalies invisible to classical cameras and scanners
- **Precision calibration and metrology:** Improving measurement stability for high-precision manufacturing processes

This matters for any sector where failure is costly: automotive, aerospace, energy systems, semiconductors, medical devices, and increasingly for advanced manufacturing methods where “you can’t inspect it later.”

Manufacturing
& Logistics

Business Values

- **Reduced waste and rework:** Earlier detection prevents defective batches, reduces scrap, and avoids costly recalls.
- **Higher product quality and consistency:** Improved measurement precision supports repeatability, compliance, and tighter tolerances.
- **Operational efficiency:** Real-time monitoring enables automated quality checks, fewer manual inspections, and faster decision-making on the shop floor.
- **New capabilities for advanced manufacturing:** Quantum sensing supports next-generation materials and processes by enabling inspection and feedback loops that weren't possible before.

Technology readiness

Quantum sensing is moving from lab breakthroughs into early commercial deployment. Several devices are already in prototype and pilot stages for industrial measurement and inspection, particularly where high sensitivity provides a clear advantage over classical tooling.

The key barrier is less about "can it measure?" and more about industrial integration: ruggedisation, cost, throughput, and connecting quantum sensors into existing QA workflows (MES, SCADA, machine vision, digital twins). As sensor costs decrease and integration pathways mature, adoption is expected to accelerate — especially for high-value production lines where even a small defect rate translates to major financial impact.

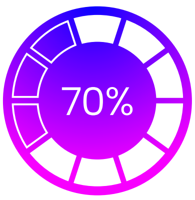
Leading players and experiments

Qnami is developing NV-diamond quantum sensing technologies that can enable ultra-sensitive measurements relevant to industrial inspection and metrology.

Zurich Instruments provides advanced instrumentation and control systems that support cutting-edge sensing and measurement setups used across quantum and industrial R&D.

Bosch and **Siemens** are actively researching how quantum-enhanced sensing and measurement can improve manufacturing precision and process monitoring.

Fraunhofer Institutes are running applied quantum sensing projects aimed at real-world industrial deployment pathways, from prototypes to system-level integration.

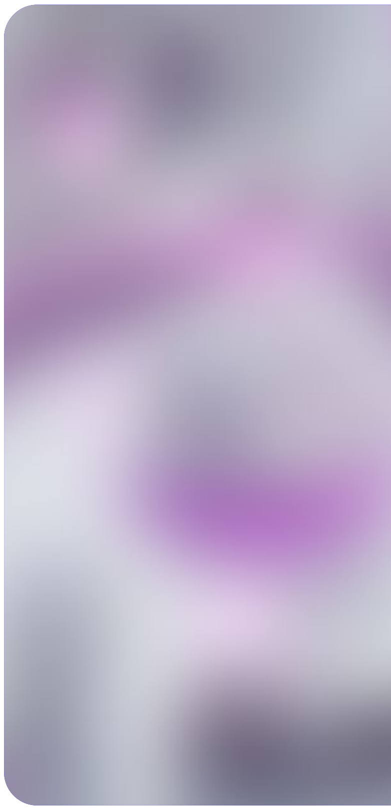


Maturity barometer

Idustrial prototypes and pilot deployments in progress.

Manufacturing & Logistics

Conclusion to the Manufacturing & Logistics series

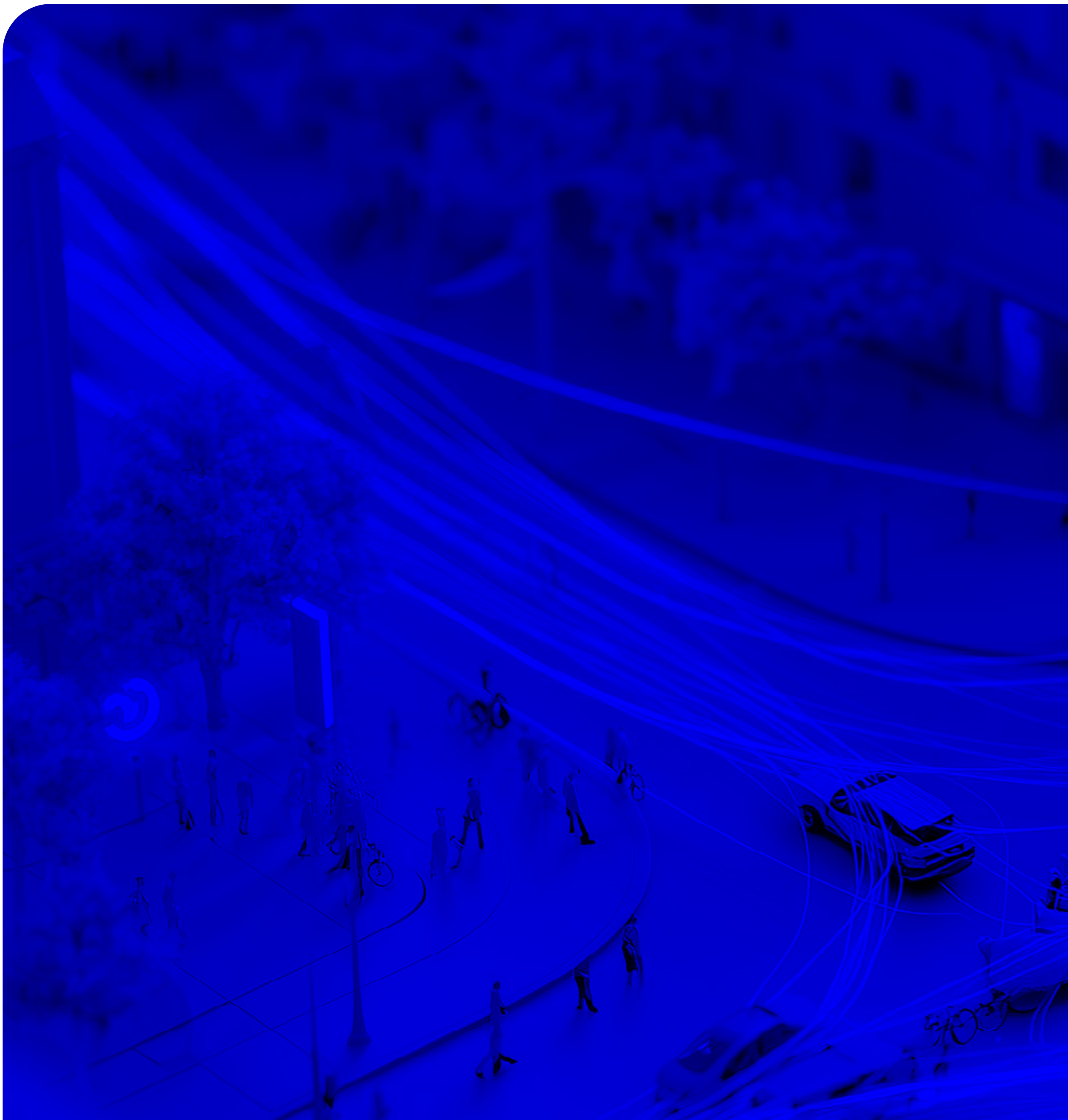


Manufacturing and logistics are entering a new era where competitive advantage is built on **optimisation, sensing, and trust**. Quantum computing helps supply chains adapt to complexity. Quantum sensing upgrades quality control from detection to prevention. And post-quantum cryptography ensures the connected backbone of Industry 4.0 remains secure, even as the threat landscape shifts.

Belgium is well-positioned to lead here: strong research capabilities, industrial know-how, and a collaborative ecosystem that connects business, technology, research, society, and ecosystems. The quantum shift won't be won by isolated breakthroughs, but by communities that turn emerging capability into real-world impact… together.

If you want to explore how your organisation can prepare, **Quantum Circle** is where Belgium's quantum ecosystem comes together to make quantum work, from pilots and partnerships to practical adoption pathways.

Discover more use cases on **quantumcircle.eu**



Quantum is here to stay, and Belgium has what it takes.

Quantum Circle, founded by Jan Sonck, is the non-profit community bringing industry, academia and government together around one question: what does your organisation do next? Honest, practical, and focused on getting you started.

Join the Quantum Circle: quantumcircle.eu