Inside Scotland's Quantum Ecosystem

From Capability to Strategic Edge

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Dr Araceli Venegas-Gomez
Founder and CEO,
QURECA

At QURECA, we have long believed that the success of quantum technologies will depend not only on scientific progress, but on the strength of the ecosystems that support them. Through our work in quantum education, workforce development, industry engagement and strategic consulting, we have seen how important it is to build the conditions that allow innovation to move beyond the lab and into meaningful economic and societal impact. Scotland stands out in this regard. It combines academic excellence, enabling industrial capability, strong photonics and semiconductor-adjacent strengths, and a collaborative culture that gives it unusual potential as a quantum ecosystem.

This is also why Scotland has been such an important focus for us, besides being QURECA's birthplace. Across our work, we have seen the value of connecting stakeholders, clarifying capability, and supporting the talent and market intelligence that help emerging sectors grow with purpose. Scotland already has many of the ingredients required for long-term leadership. The task now is to ensure those strengths are coordinated, visible and translated into lasting advantage.

This report is an important contribution to that effort. It brings together a strategic view of Scotland's position, its infrastructure and supply base, its commercial opportunities, and the workforce foundations that will shape its future. The report shows clearly that Scotland's opportunity is not only in discovery, but in becoming an enabling economy with strong workforce foundations needed to support future growth. My hope is that it will support stronger collaboration, clearer direction and a confident long-term vision for Scotland's role in quantum technologies.

Abhishek Purohit
Technology & Strategy, QURECA
Doctoral Researcher, University of Glasgow

Scotland holds a distinctive place in the quantum landscape, shaped not only by research excellence but by the enabling capabilities and infrastructure that give it real strategic relevance within the UK. This report was developed to understand where that advantage is strongest, what is holding it back, and what is needed to turn existing capability into lasting industrial value. Across this report, we have structured that assessment around four core pillars: strategic positioning, commercialisation and adoption, infrastructure and testbeds, and skills and talent. Together, these provide a more complete view of how Scotland's quantum ecosystem functions and where it can create the greatest long-term advantage.

What emerges clearly is that Scotland's opportunity is not to win a single modality race, but to establish itself as an enabling and integration economy for deployable quantum systems. Its strengths lie in photonics, semiconductors-adjacent capability, research infrastructure, workforce depth, and a dense, collaborative ecosystem that already plays a disproportionately important role within the UK quantum architecture. The challenge now is one of translation: ensuring that these strengths lead to scalable products, trusted supply-chain positions, stronger adoption pathways, and lasting value capture.

It is my hope that this report will serve not only as an assessment of where Scotland stands today, but as a practical contribution to shaping what it can become over the next decade.

Richard Lochhead
Former Member of the Scottish Parliament and Minister for Business and Employment

I am pleased to hear about QURECA's work in bringing together insights from across the sector to inform future strategy and action.

Scotland is home to internationally recognised clusters including space, fintech, energy and life sciences, all supported by a strong academic base, and it is this cluster building approach that the Scottish Government is using as its lever to deliver growth in areas such as quantum.

As I am sure you will be aware in quantum, two of the UK's five Quantum Centres for Doctoral Training are based in Scotland, and Scottish institutions play key roles in all five UK Quantum Hubs. The University of Edinburgh, home to the UK's current national supercomputer, will also host the next generation supercomputer and is global hub for leaders in AI. Scotland boasts the only Fraunhofer CAP in the UK, alongside other translational assets such as the James Watt Nanofabrication Centre.

Our close connection with major financial institutions such as several of the UK's largest banks creates an ideal setting for piloting quantum-enabled financial and data applications and advancing the objectives of the UK's quantum strategy.

Much of this builds on Scotland's long-standing expertise in photonics which we are harnessing with our Critical Technologies Supercluster initiative. This recognises the many technical and ecosystem synergies across quantum, photonics, semiconductor and sensing sectors.

With over 150 companies, 11,000 employees, and generating £4.2 billion in annual turnover, this supercluster is a strong vehicle for economic growth and is on track to reach £10 billion in revenue and 17,500 jobs by 2035.

Professor Sir Peter Knight

Chair of the UK National Quantum Technology Programme Strategy Advisory Board

Scotland plays an extremely important role in a number of areas within the UK quantum landscape, particularly in the supply chain, components and enabling technologies. There is a very strong concentration in photonics activity in central Scotland belt, and that is an enabler for a whole raft of quantum technologies. Without some of those activities, a lot of what is going on across the UK would not actually be possible.

Scotland is also very important in terms of research infrastructure and skills. Facilities such as the James Watt Nanofabrication Centre in Glasgow are a really important early-stage capability for building demonstrators and prototypes, and most of these infrastructures and organisations are no more than an hour away from each other, so what you have got is a hub of excellence, an industrial presence through the laser systems, and a real regional intent on making this work. The Scottish universities, especially the central-belt universities, have also become quite good at working together, adding together strengths rather than competing, and that makes the ecosystem very attractive to companies.

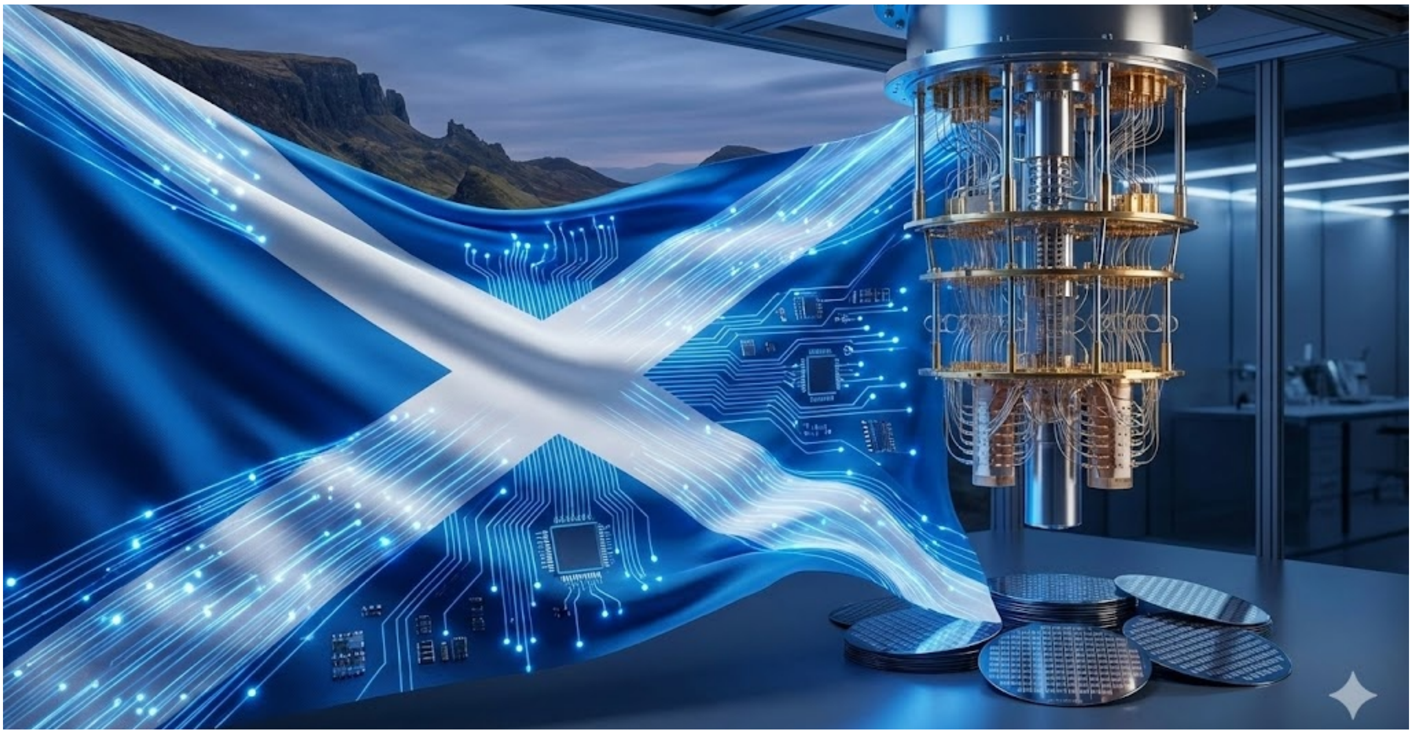
The challenge now is scale. Scotland has real strengths in sensing, imaging, photonics and workforce, but the big remaining element of the puzzle is scale-up infrastructure and patient capital investment. Unless we address that, we risk failing to capture the rewards of the leadership and investment already built up over the past decade. What we will see, through mergers and acquisitions, is the largest-scale expectation being built elsewhere. We need to make this activity sticky in the UK, and Scotland is well placed to help do that.

CHAPTER

01

Quantum Scotland

Positioning Scotland in the UK and global quantum economy



Executive Summary

Scotland's quantum opportunity is not to win a single modality race. It is to become the place global buyers come to for components, supply chain demand, and deployable quantum systems: providing repeatability, integration and supplier-qualified subsystems at scale.

1. Global demand is converging around hard technical bottlenecks (fabrication, integration, error, packaging, SWaP-C (Size, Weight, Power and Cost), and reliability rather than around research novelty alone.
2. Scotland's defensible advantage is modality-agnostic: enabling hardware and integration capabilities required across computing, sensing and communications.
3. Scotland's quantum clusters already act as a key connector in the global ecosystem, with unusually strong external collaboration and a central broker role, meaning they sit between many organisations and routinely link partners globally who would not otherwise work together. This position gives Scotland influence over which collaborations form and, over time, the standards, architectures and suppliers that get adopted.
4. The primary execution risk is value leakage: exporting knowledge while importing high-value subsystems. The job is to convert brokerage into contracting power by owning qualification, integration and validation.

Scotland should position itself as the engine room of the global quantum stack, specialising in the enabling layer and the translation infrastructure that closes the TLR (Technology Readiness Level) 4 to TRL 9 deployment gap.

Findings	Implication	Scotland-specific mitigation
Scotland is already acting like a connector node in the global quantum graph, not just another cluster. The "hidden asset" is brokerage: Scotland sits where partnerships form and systems get stitched together.	If Scotland stays a component economy, that brokerage turns into leakage. We will keep building the hardest parts while the system margin, the branding and the repeat contracts accrue elsewhere.	Build a Scottish system integration and packaging hub whose purpose is to turn isolated enabling components into functional systems. Fabrication, integration, packaging and acceptance testing should be developed as national capabilities so that SMEs can collaborate more easily, sell qualified subsystems, and move beyond supplying individual parts.
The uplift story in Chapter 1 is not "more quantum firms". It is bottlenecks. Photonics, semiconductors-adjacent capability and the control stack are where quantum concentrates value because every modality must pass through them.	The risk is a scale-up cliff. Quantum scales with heavy infrastructure investment. If Scotland cannot finance and access the heavy kit needed for production, test and reliability, we will incubate winners then lose them when they try to scale.	Create subsidised **capex-as-a-service** for the cluster: state-backed leasing and shared access to the specific bottleneck equipment / facilities / services necessary for quantum technologies. Keep manufacturing gravity and IP anchored in Scotland.
Scotland has a uniquely "buyable" national test canvas: concentrated public infrastructure, energy transition assets and a cohesive set of institutions that can act as early adopters when the technology is still risky.	Without a domestic anchor customer, quantum struggles to move past the pilot phase. Buyers do not procure promise; they procure proof under operating conditions and Scotland loses time while others accumulate reference deployments.	Run a proxy prime procurement programme: commit a small, ring-fenced slice of public spend to first-of-a-kind quantum deployments in Scotland (energy networks, maritime, health, resilience). The output is not reports, it is reference sites and purchase orders that make Scottish tech exportable at premium margins.

1.

Scotland in the quantum revolution

To understand Scotland's future role in the quantum economy, we must look beyond abstract capability and focus on the mechanics of global demand. As value consolidates around specific technical bottlenecks, Scotland is uniquely positioned to offer a solution: a distinctive convergence of deep science, enabling hardware, and networked collaboration.

The regional imperative is to convert these raw strengths into a commercial engine. Success depends on our ability to industrialise the right components of the quantum stack at pace, ensuring that when the global market accelerates toward large-scale procurement, Scotland is not just a participant, but a primary supplier of scalable, high-value systems.

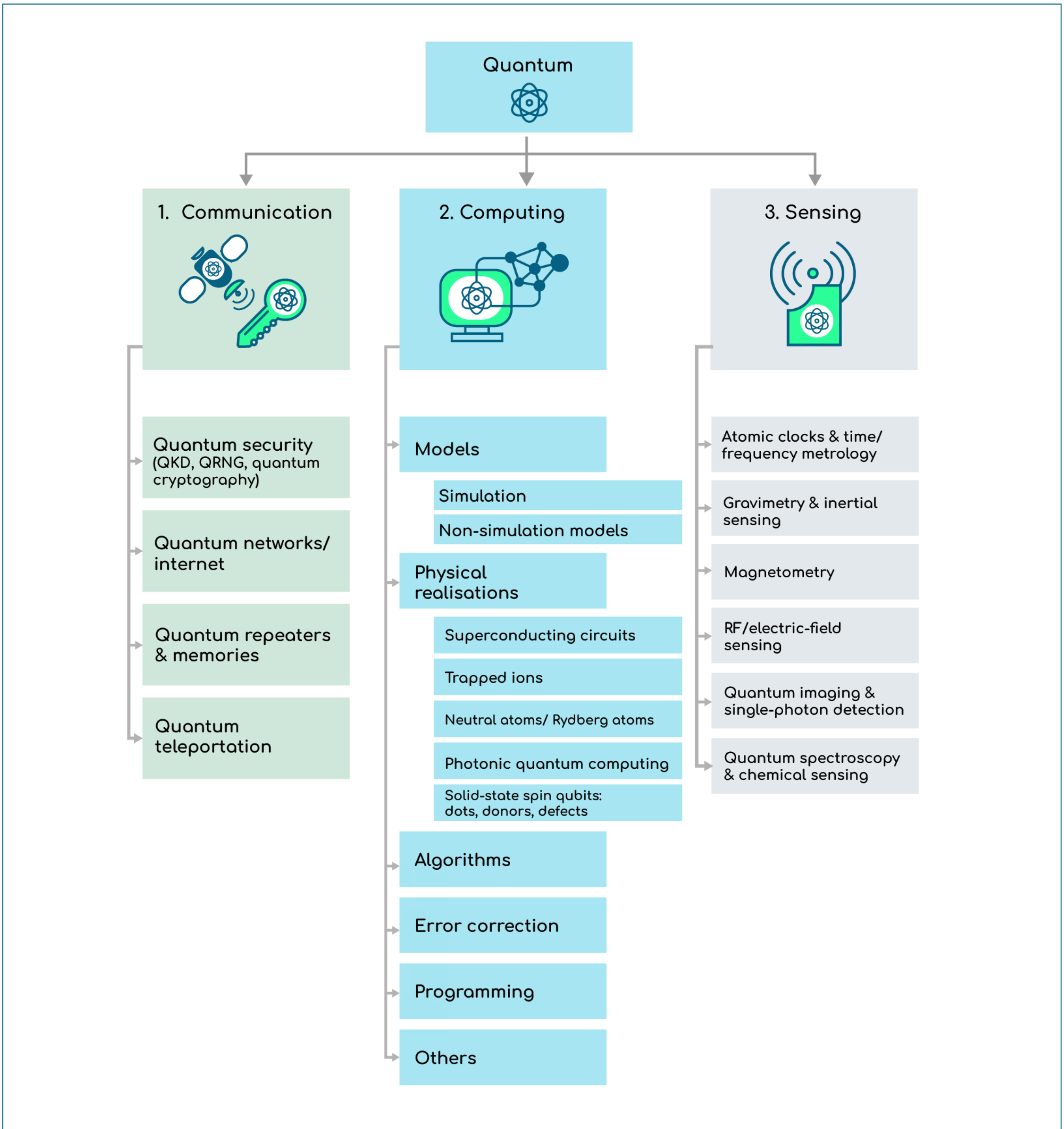


Fig.1.1: Quantum technologies grouped into communication, computing and sensing, with the main sub-areas listed under each pillar (non-exhaustive).

1.1

The transition from scientific curiosity to industrial imperative

The global technological order is navigating a "phase transition" of historical magnitude. We are shifting from the probabilistic exploitation of quantum mechanics which gave us the transistors and the laser to the deterministic engineering of individual quantum states. This "second quantum revolution" is no longer a scientific frontier; it is a fundamental reordering of industrial hierarchy. The second quantum revolution represents a definitive strategic pivot from the passive utilisation of collective quantum effects to the active engineering and control of individual quantum states, specifically superposition and entanglement. This shift was not fuelled by scientific breakthrough alone, but by the convergence of technological maturation and geopolitical imperative[1,23].

[1] OECD (2025) An overview of national strategies and policies for quantum technologies. OECD Digital Economy Papers, No. 379. OECD Publishing: Paris. https://doi.org/10.1787/5e55e7ab-en

[2] Goorney, S.R., Aslan, E., Baskakovs, A., Muñoz, B. and Sherson, J. (2026) 'National Quantum Strategies: A Data-Driven Approach to Understanding the Quantum Ecosystem', arXiv, 2601.16329. https://doi.org/10.48550/arXiv.2601.16329

[3] Purohit, A., Kaur, M., Seskir, Z.C., Posner, M.T. and Venegas-Gomez, A. (2024) 'Building a quantum-ready ecosystem', IET Quantum Communication, 5(1), pp. 1–18. https://doi.org/10.1049/qtc2.12072

Technology	Potential advantage	End-sector advantages	Current limitations
Quantum communications and security	1. Create encryption keys in a way that makes interception detectable. 2. Support frequent key refresh for high-value links. 3. Provide reliable true randomness for security systems.	**Defence and government:** high-assurance links and comms integrity. **Finance:** interbank, trading, key management resilience. **Telecom and data centres:** premium secure links and key refresh at scale. Critical infrastructure: grid control, SCADA key protection. **Defence and aerospace:** satellite QKD and secure ground-to-space links.	1. Range-rate-cost trade-offs in fibre and free-space. 2. Repeaters not yet practical at scale (memories, rates). 3. Operational integration and standards still maturing.
Quantum computing	1. Tackle a set of complex calculations that overwhelm today's computers, once the technology scales. 2. Let industry test molecules and materials in software first, cutting time and cost in R&D for the right problems. 3. Offer speedups for some planning and optimisation tasks where this is proven against classical methods.	**Materials and chemicals:** catalysts, batteries, corrosion pathways. **Drug discovery:** reaction energetics, binding workflows. **Finance:** portfolio and risk methods. **Logistics and manufacturing:** constrained optimisation. **Cyber:** cryptanalysis risk long-term, drives crypto migration now.	1. Limited to specific problem classes. 2. High error rates. 3. Many platforms need extreme cooling.
Quantum simulation	1. Reproduce complex quantum behaviour directly, where classical models scale poorly. 2. Predict properties of strongly correlated materials and reaction dynamics with better fidelity in targeted regimes. 3. Reduce time-to-insight for specific materials and chemistry questions.	**Materials:** strongly correlated systems, superconductivity candidates, magnetism. **Energy:** batteries, ammonia synthesis, CO^2 reduction catalysts. **Semiconductors:** defect physics, dopants, interface chemistry. **Pharma:** accurate reaction mechanisms. **Defence and aerospace:** materials or sensors, coatings and extremes.	1. Validation is the bottleneck. Noise and errors correction overhead. 2. Limited qubit counts. 3. Translating outputs into engineering specs is nontrivial.
Quantum sensing and metrology	1. Measure time, motion and very weak signals more precisely than classical sensors in the right conditions. 2. Enable new capabilities such as navigation without GPS and better underground or underwater mapping. 3. Improve accuracy and stability for timing and synchronisation that digital infrastructure depends on.	**Defence and security:** navigation without GNSS, magnetic anomaly, subsurface. **Aerospace:** precision timing, inertial sensing, space-qualified clocks. **Energy and geophysics:** gravimetry for subsurface mapping and monitoring. **Healthcare:** brain and cardiac field sensing. **Manufacturing:** non-destructive testing, process control.	1. Field performance limited by environment and calibration. 2. SWaP, ruggedisation and cost are often dominant constraints. 3. Deployment certification and procurement cycles are long.

Table 1.1: Strategic overview of quantum technology domains, advantages and limitations (non-exhaustive).

As enabling hardware (such as cryogenics, electronics and photonics) reached industrial-grade reliability, global powers recognised that quantum dominance was no longer an academic pursuit but a requirement for technological sovereignty. The acceleration of this revolution is driven by two powerful engines: national security anxiety regarding the vulnerability of current encryption, the need for a powerful PNT (Position, Navigation and Timing) infrastructure, and a massive influx of private capital seeking to unlock trillions in value through drug discovery and complex optimisation.

Consequently, the global quantum landscape has transformed from a collaborative scientific field into a high-stakes race for industrial and defensive supremacy.

The global signals are now consistent enough to guide strategy. Across national quantum strategies, the most frequently prioritised application areas are those tied to sovereign resilience and critical infrastructure: cybersecurity leads, followed closely by transport and defence and national security, with materials science being also prominent (Figs. 1.2, 1.3).

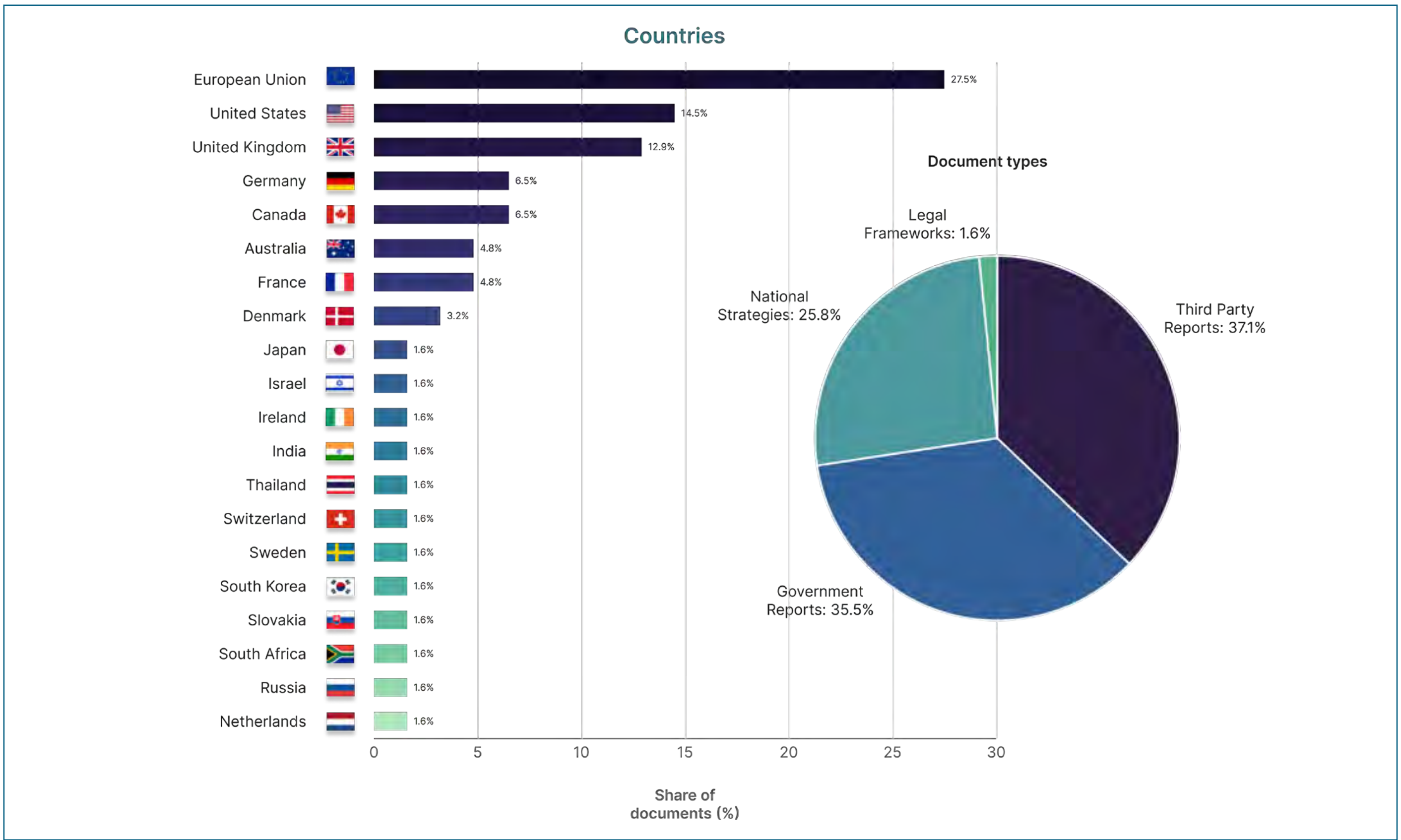


Fig.1.2: Percentage of global strategy documents mentioning specific fields of application.

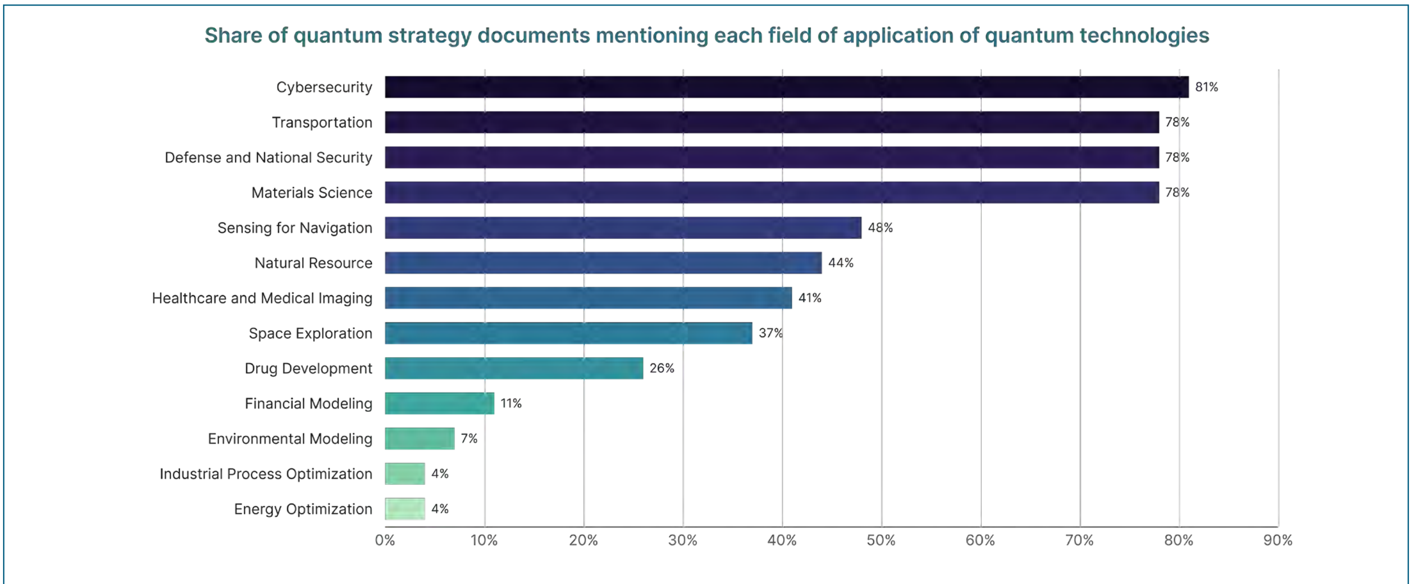


Fig.1.3: Distribution of quantum strategy documents by issuing country and document type.

1.2
Global market dynamics

Quantum is not a single market moving at a single speed. The provider market projections show three distinct trajectories across computing, communications, and sensing (Fig 1.4). Computing carries the highest ceiling by 2040, but communications and sensing are materially sized, nearer-term, and often closer to field deployment because they integrate into existing infrastructure and procurement pathways. Public investment[4] is also uneven across regions and it shapes where testbeds, procurement and supplier relationships consolidate first. Fig. 1.5 summarises announced national quantum funding commitments and shows the concentration of long-horizon programmes that will anchor early demand for enabling technologies. That timing matters for Scotland's strategy. Ecosystems that bet only on the "winner" of the qubit modality race risk waiting for a single platform to mature. Scotland's most defensible position is modality-agnostic: sell into the enabling layer that is required regardless of whether superconducting, trapped-ion, neutral-atom, or silicon spin approaches dominate. In practical terms, that means prioritising the industrial stack that sits beneath all three pillars: lasers and optics, control and RF electronics, packaging and integration, metrology, and the engineering talent that makes the stack reliable at scale.

A second implication follows. Because the market inflects sharply post-2030 in the mid-case trajectory[5,6,7,8], supply-chain positions that look optional today become locked-in relationships later.

The window for Scotland to secure default-supplier status is earlier than the window for Scotland to see full market-size revenues. That gap is precisely where government-backed programmes, demonstrators, and integration infrastructure determine who captures the supply chain.

[4] QURECA (n.d.) Quantum Initiatives Worldwide. https://www.qureca.com/quantum-initiatives-worldwide/

[5] McKinsey & Company (2025) Quantum Technology Monitor: The Year of Quantum — From Concept to Reality. https://www.mckinsey.com/capabilities/tech-and-ai/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025#/

[6] Colwell, B.D. (2025) 2025 Quantum Computing Industry Report and Market Analysis: The Race to $170B by 2040. https://briandcolwell.com/2025-quantum-computing-industry-report-and-market-analysis-the-race-to-170b-by-2040/

[7] World Economic Forum (2024) Quantum Economy Blueprint. WEF: Geneva. https://www.weforum.org/publications/quantum-economy-blueprint/

[8] The Quantum Insider (2025) Where's the Real Money in Quantum? Quantum Vendors to Capture Just 6% of Total Projected Impact. https://thequantuminsider.com/2025/08/04/wheres-the-real-money-in-quantum-quantum-vendors-to-capture-just-6-of-total-projected-impact/

Rank	Cluster	Country	Key Characteristic
1	Cambridge	UK	Academic & Tech Ecosystem
2	Greater Helsinki	Finland	Cryogenics & Hardware
3	Oxford	UK	Academic Maturity
4	San Francisco Bay	USA	Venture Capital & Software
5	Greater Glasgow	UK	Brokerage and Collaboration

Table 1.2: Top 5 Global Quantum Clusters (2025 Ranking)

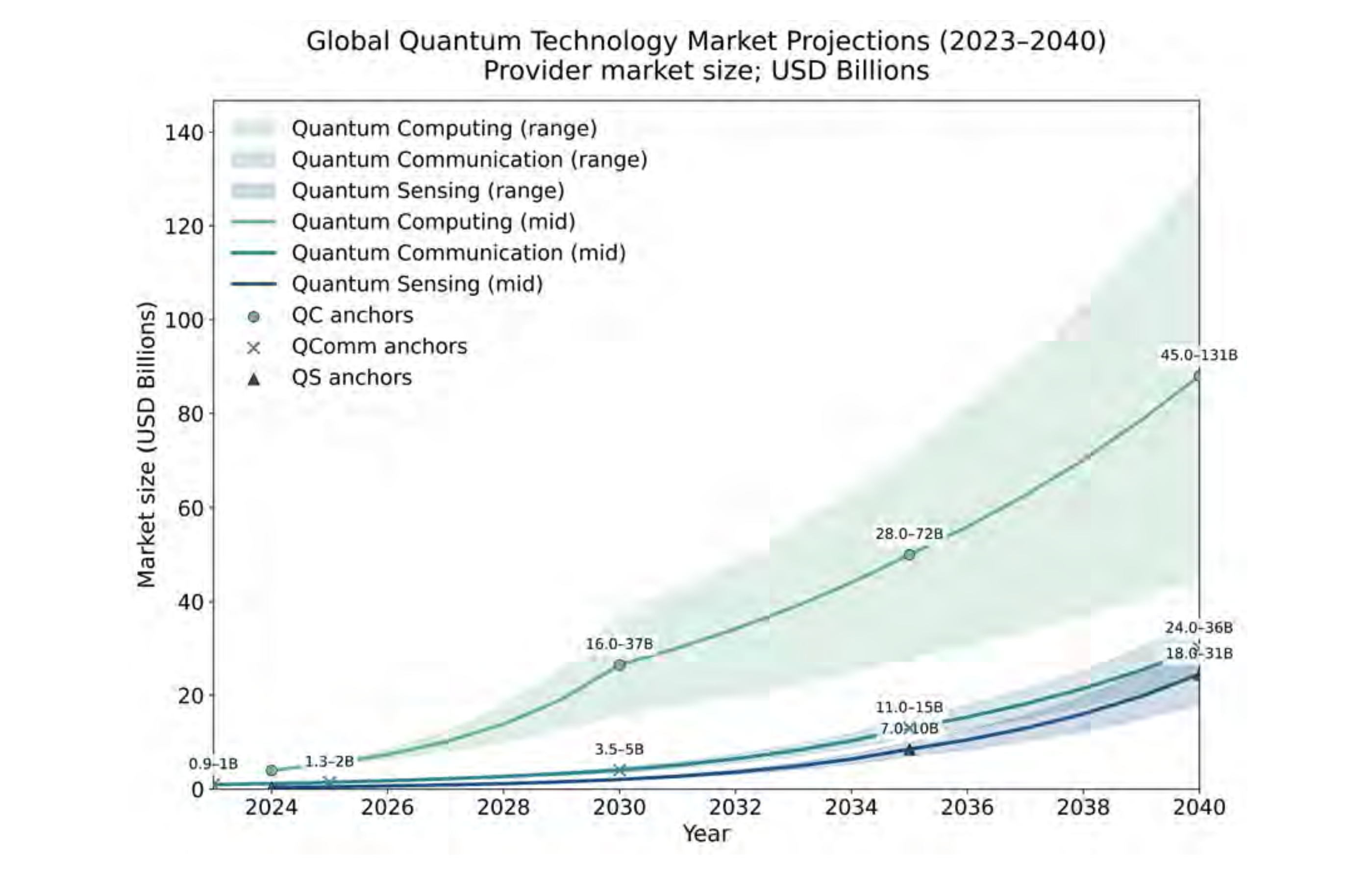


Fig.1.4: Global Quantum Technology provider market projections (2023–2040) for computing, communication, and sensing, with midline forecasts and low–high ranges.

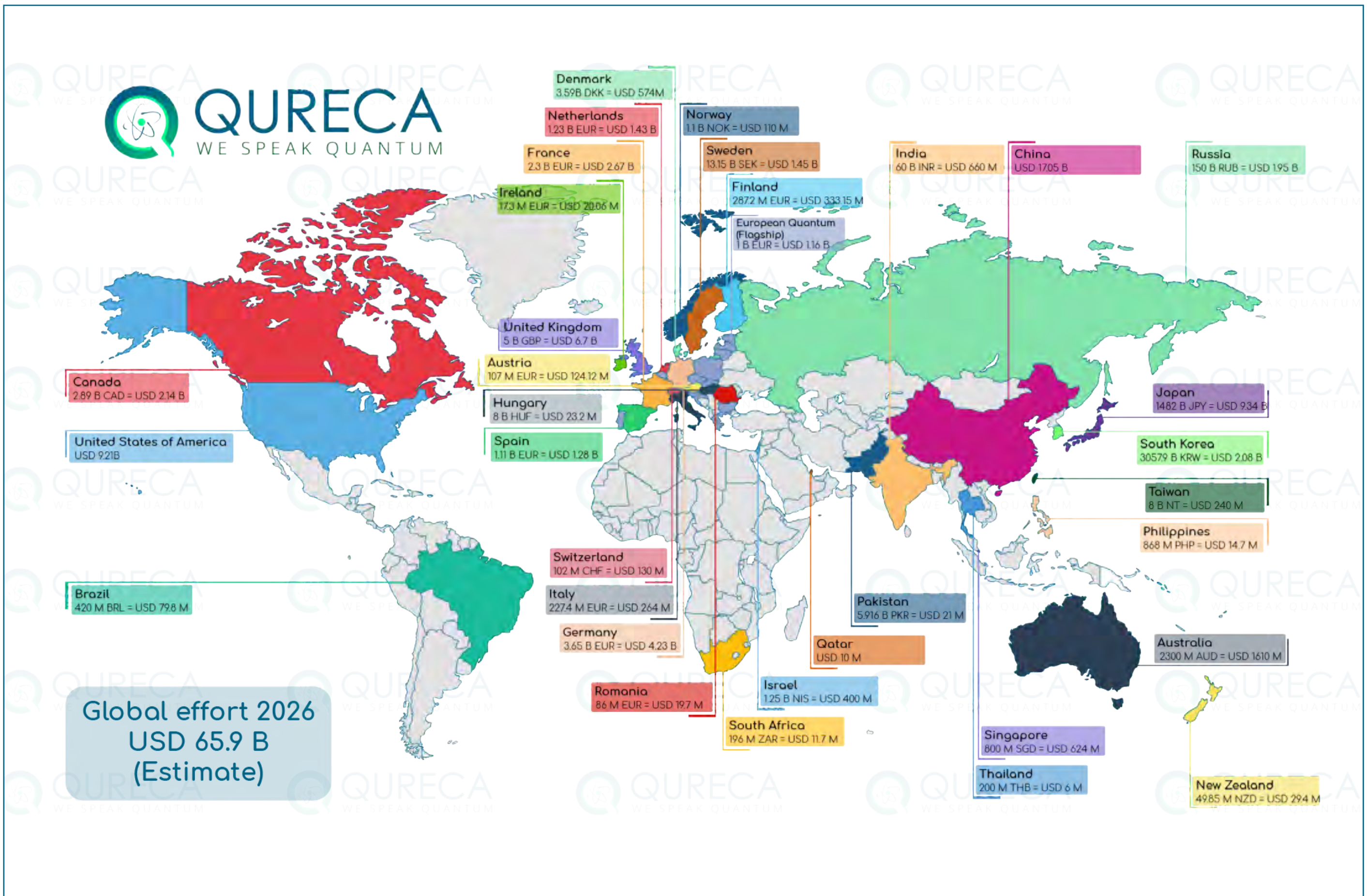


Fig.1.5: Global quantum initiatives and public investment commitments by country (latest announced programmes). Coloured regions indicate national initiatives and indicative funding levels. Source: QURECA (2026)

1.3
Connectivity and brokerage

Funding alone does not explain capability leadership. Quantum advantage concentrates in clusters because the value chain is unusually interdependent, and iteration cycles rely on proximity between fabrication, system integration, and end-user validation. In global cluster terms, Greater Glasgow is already positioned in the top tier (Fig 1.6). The cluster ranking places it 5th worldwide, alongside the most established deep-tech epicentres[9]. It is reinforced by network structure: Greater Glasgow shows exceptionally high external collaboration and a strong brokerage centrality score, meaning it functions as a high-connectivity bridge across institutions and regions. For the regional strategy, brokerage has a clear "so what?".

Clusters with high brokerage tend to influence standards, integration pathways, and supplier selection because they sit at the junctions where partnerships form. They see more of the system, earlier. They also become preferred sites for integration work because they can pull in capabilities fast. Scotland therefore has a genuine opportunity to become a global integrator node. Brokerage also carries a risk that needs to be addressed.

If Scotland primarily exports knowledge and prototypes while importing high-value subsystems, brokerage becomes value leakage. The job is to convert brokerage into contracting power: making Scotland the place where components are qualified, systems are integrated, and repeatable deployments are validated, so that supply-chain revenue accrues locally rather than being captured downstream.

[9] Erixon, F., Dugo, A. and Pandya, D. et al. (2025) Quantum Clusters: Ranking the World's Deep-Tech Epicentres. European Centre for International Political Economy: Brussels. https://ecipe.org/publications/quantum-clusters-ranking-deep-tech-epicentres/

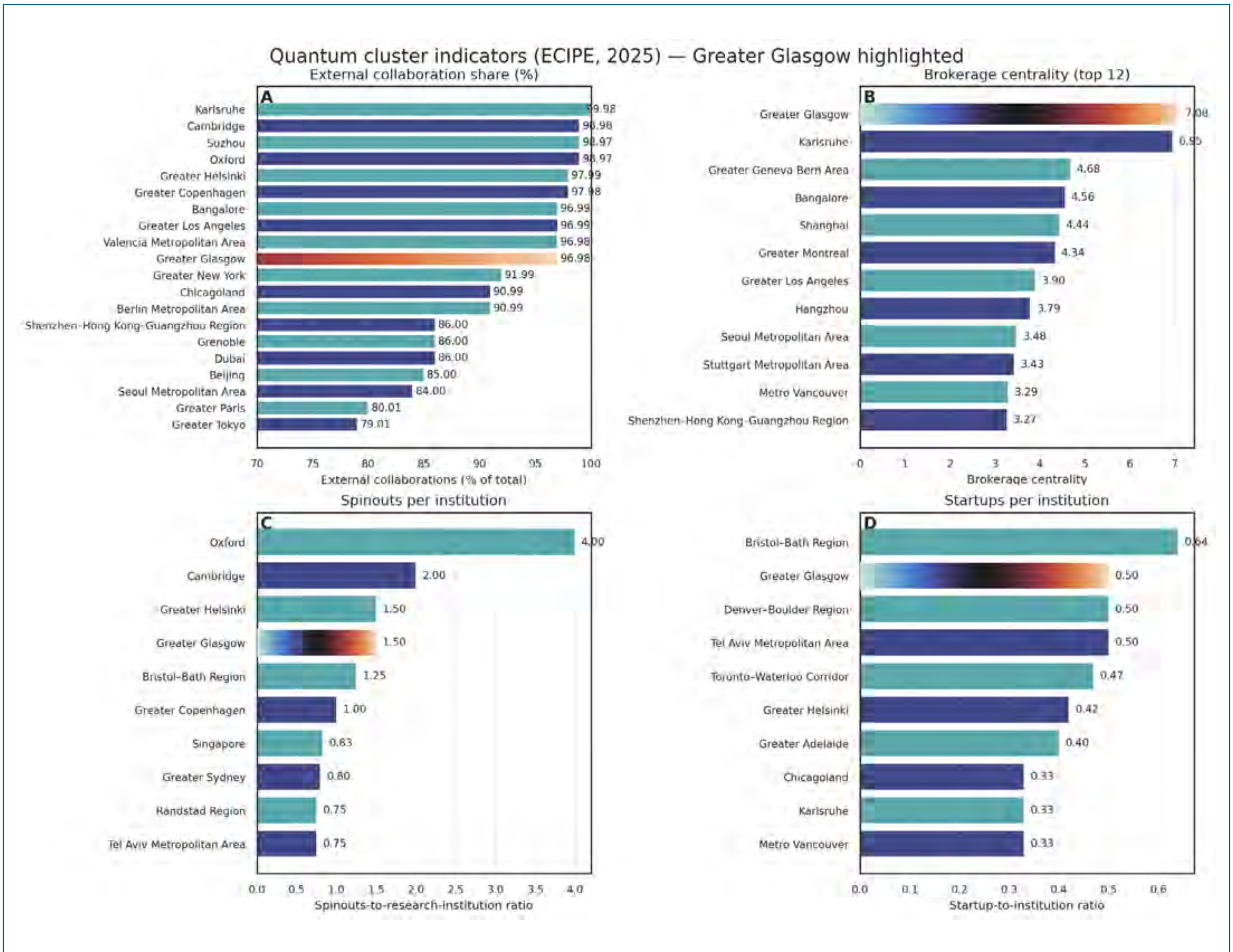


Fig.1.6: Cluster characteristics for Greater Glasgow in 2025 ECIPE Quantum Clusters benchmark. The plots compare external collaboration share, brokerage centrality and spin-out and start-up intensity per institution[9].

1.4
Strategic positioning

To frame Scotland's opportunity, we must first understand the specific friction slowing the global market. The World Economic Forum identifies a critical deployment deficit in the global market[10]. While the appetite for adoption is high, the supply chain lacks the industrial maturity to deliver reliable, standardised solutions, leaving a vacuum between Technology Readiness Level (TRL) 4 and TRL 9 that Scotland is uniquely positioned to fill. While scientific momentum is undeniable the technology "has yet to demonstrate advantage at scale," largely due to fidelity issues that hinder broader commercial adoption. Crucially, BCG predicts that up to 10% of the market's value will flow not to the quantum processors themselves, but to the enabling supply chain[11].

A useful way to frame Scotland's proposition is to ask what global buyers struggle to buy today. They can often buy prototypes. They struggle to buy repeatability, integration and support at scale. Scotland's advantage is that it can credibly become a deployability economy for quantum: a place where research strength is coupled to enabling supply chains, engineering capability and an increasingly coherent national pathway from lab to product. That is a different claim from simply having many quantum firms. It is a claim about owning the mechanisms that convert technical novelty into operational systems. This is also where national culture becomes an economic variable. Quantum adoption is not only a technology challenge.

It is a coordination challenge. Ecosystems that can align universities, suppliers, integrators, end users and public programmes around shared roadmaps will outcompete ecosystems that remain fragmented, even if both are scientifically strong.

[10] World Economic Forum (2025) Quantum Technologies: Key Opportunities for Advanced Manufacturing and Supply Chains. WEF: Geneva. https://www.weforum.org/publications/quantum-technologies-key-opportunities-for-advanced-manufacturing-and-supply-chains/

[11] Boston Consulting Group (2024) The long-term forecast for quantum computing still looks bright. BCG: Boston. https://www.bcg.com/publications/2024/long-term-forecast-for-quantum-computing-still-looks-bright

UK National Hub	Primary Focus	Strategic Significance
QEPNT Hub	Position, Navigation & Timing	Critical National Infrastructure (GPS resilience)
QuSIT Hub	Sensing, Imaging & Timing	Medical Imaging, Defence Sensing
IQN Hub	Integrated Quantum Networks	The "Quantum Internet," Secure Communications
QCi3	Computing (Integrated)	Hardware Integration
Q-BIOMED Hub	Biomedical Sensing	Healthcare Applications

1.5
Scotland as part of national capability

Scotland's strength is not only global; it is deeply embedded in the UK's national quantum architecture. Fig 1.7 shows Scotland's share of the UK National Quantum Technologies Programme varies from 11.8% to 63% across the different hubs. According to the UK Department for Business and Trade, the Scottish cluster has been responsible for approximately 40% of the UK's research in quantum technologies over the last decade, a figure far exceeding its population share and signalling sustained industrial R&D intensity[12].

This density is one reason Scotland can credibly pursue an enabling-stack strategy. It has both the research throughput and the cross-domain adjacency required to convert individual breakthroughs into system-level capability. A dense local base of quantum and enabling firms (Fig. 1.8) creates the missing industrial continuity between funded programmes and deployable systems. When firms across the quantum stack and its enabling layers co-locate at a meaningful density, the ecosystem behaves like a single production line: faster handoffs from lab to supplier, tighter integration between components and software, and lower friction in forming consortia that can actually ship and support systems. That density advantage is what turns participation into pull-through.

[12] Department for Business and Trade (2025) Quantum Technologies: Investment Opportunities in the UK. HM Government: London. https://www.business.gov.uk/invest-in-uk/investment/sectors/quantum-technologies/

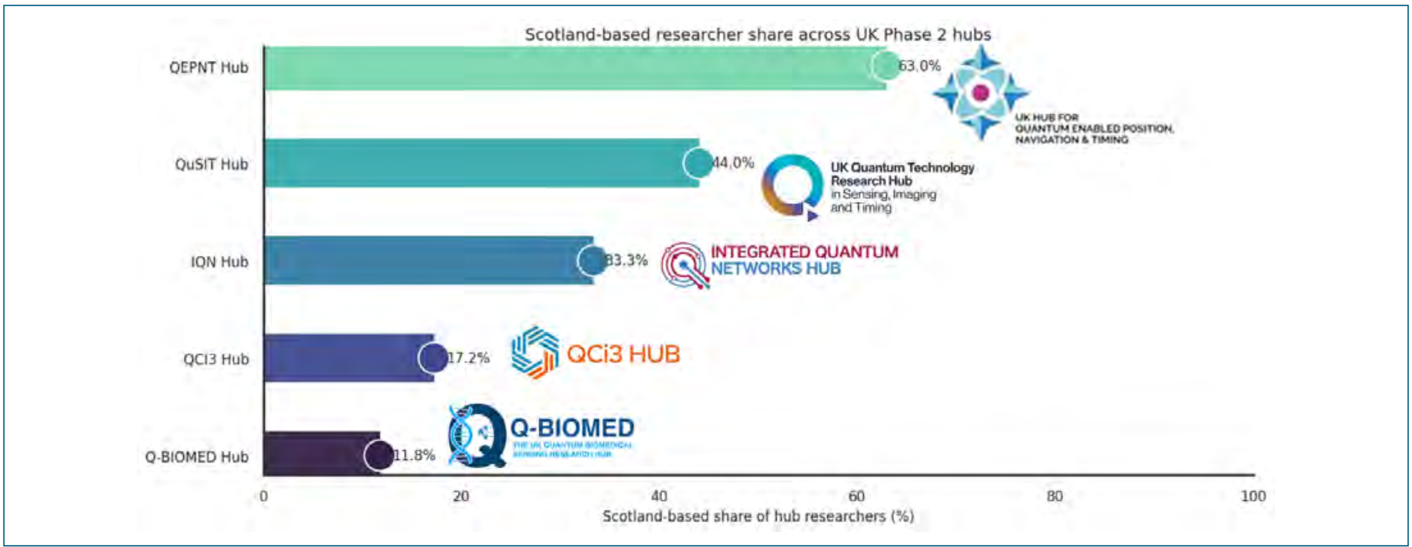


Fig.1.7: Scotland's share of UK National Quantum Technologies Programme Phase 2 hub participation.

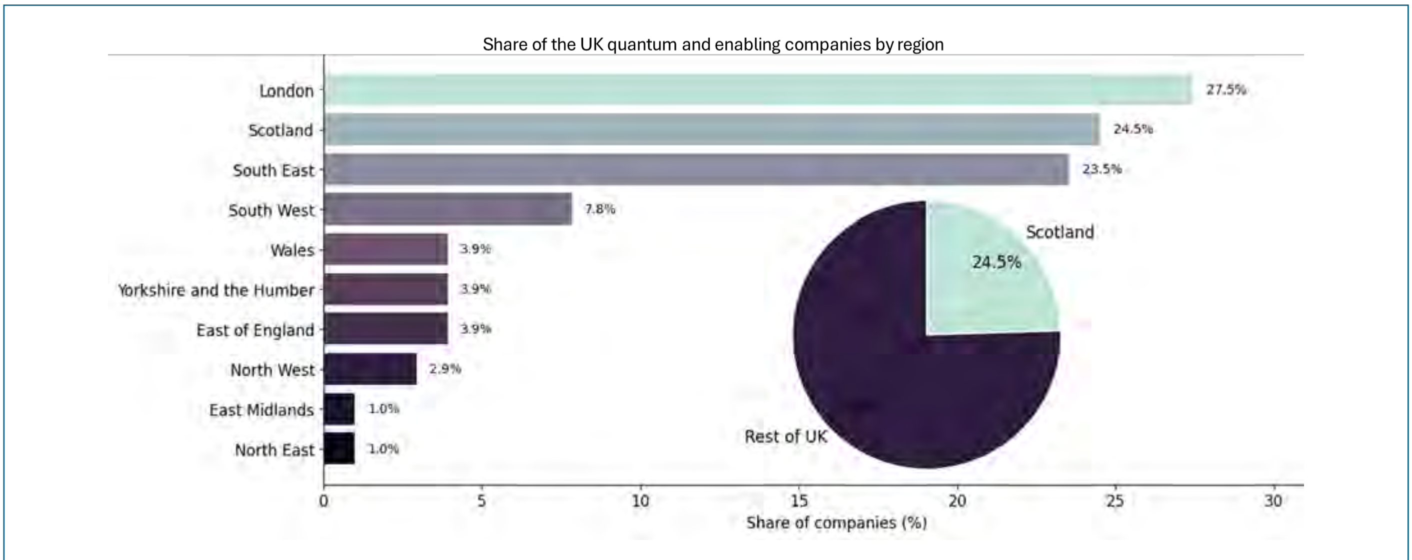


Fig.1.8: Scotland accounts for 24.5% of mapped UK quantum and enabling companies, evidencing a high-density base that strengthens local supplier adjacency and accelerates research-to-deployment iteration. Source: QURECA Database.

1.6
Scotland's policy environment as an enabler

Scotland's economic strategy already has the right execution bed for quantum technologies: treat it as a mission-grade capability where value capture depends on coordinated delivery, not isolated breakthroughs. The national direction emphasises innovation-led growth, new markets, scale-up and system collaboration (National Strategy for Economic Transformation, Scottish Government; National Innovation Strategy 2023–2033, Scottish Government)[13].

The opportunity now is to use existing policy levers in a distinctly smart way, with ministers setting the tempo and removing friction between research, industry and end users. Scotland can use procurement as an early market signal. The Scottish Government can commission challenge-led pilots that force real requirements around assurance, integration and operations.

[13] Scottish Government (2022) Scotland's national strategy for economic transformation. Scottish Government: Edinburgh. https://www.gov.scot/publications/scotlands-national-strategy-economic-transformation/

These can use mechanisms proven to run R&D; procurement at pace, such as CivTech. In parallel, create more regional dedicated funding pathways for quantum technologies. Second, turn supplier qualification into Scotland's moat. Back this by investing in enabling infrastructure, shared test, metrology and compliance pathways. This helps firms move from prototype to trusted supplier and qualify into global programmes. Third, scale what works with patient capital that crowds in private co-investment for hardware and enabling supply chains, where timelines are long, but export value is durable (Scottish National Investment Bank). The ministers' involvement is valuable precisely because quantum needs a joined-up operating model. Left to itself, it fragments into excellent research plus scattered pilots. With the right strategic design, it becomes a conversion engine.

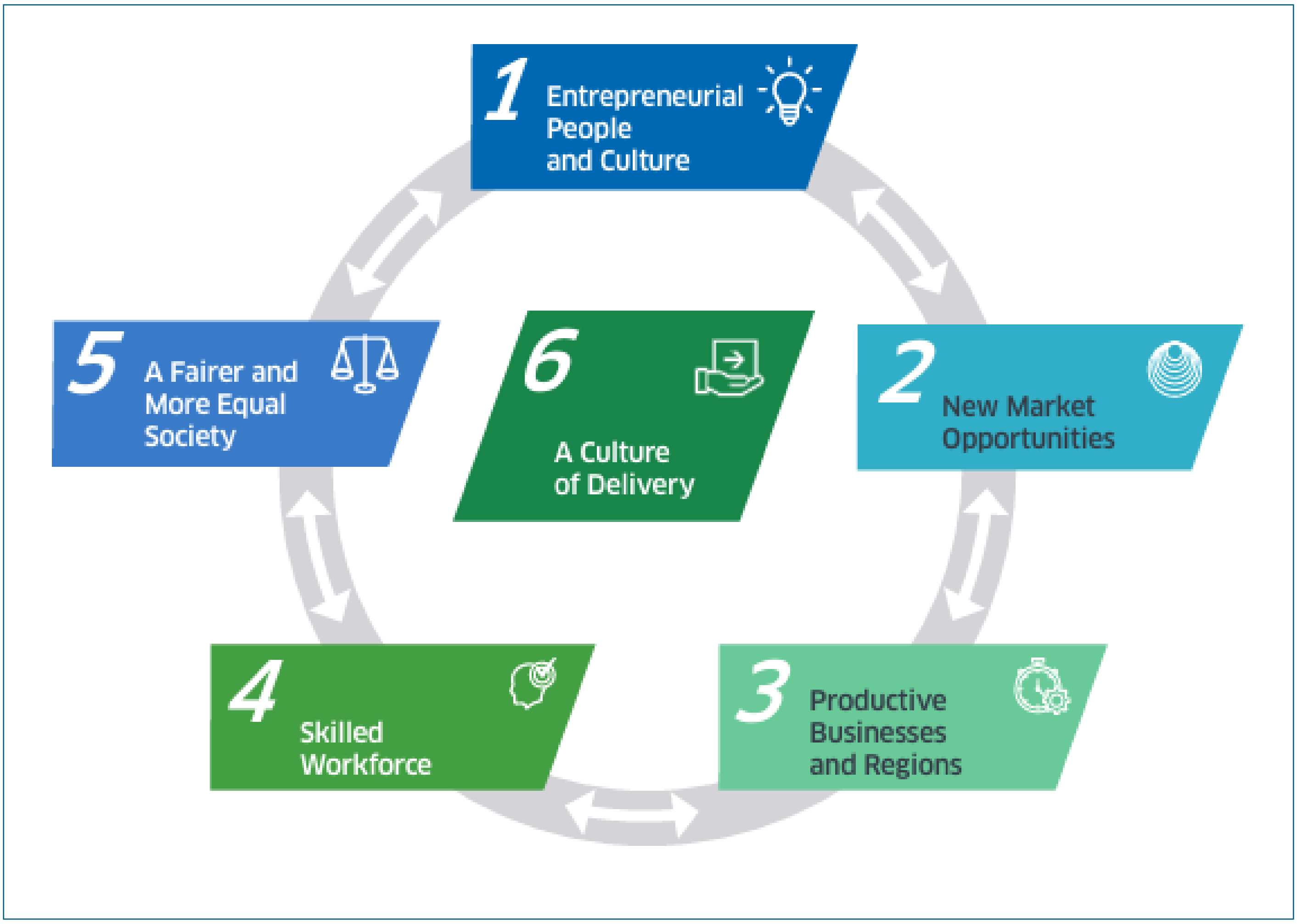
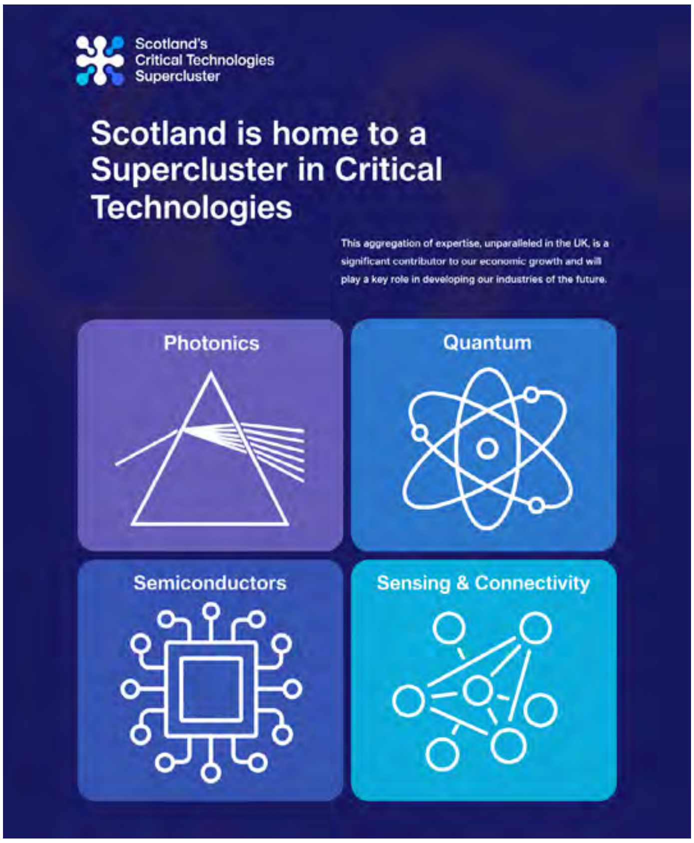


Fig. 1.9: Scotland's policy programmes of action form a cycle with delivery at the centre.

1.7
Scotland's Critical Technologies Supercluster

The most credible positioning for Scotland is not "quantum as a silo". It is quantum as a multiplier that strengthens adjacent strategic industries, especially photonics and semiconductors, and the enabling electronics and software that connect them. Scotland's own advisory and industry-facing framing increasingly reflects this logic: photonics, semiconductors and quantum are treated as interlocking capability pillars tied to economic transformation and export opportunity. Its purpose is to convert Scotland's strengths across quantum, photonics, semiconductors and sensing/ connectivity into a single, buyable proposition that accelerates TRL progression and makes supply chains easier to qualify into global programmes. Done well, it tightens the link between shared translation infrastructure, investor confidence and early customer pathways, while strengthening strategic resilience in sectors where security, net zero, transport and advanced industry drive adoption[14]. The guiding principle is simple: grow the enabling workforce and the deployment-facing capabilities that turn research excellence into repeatable systems and exportable subsystems.

[14] Scottish Science Advisory Council (2025) Scotland's Critical Technologies Supercluster: Challenges and Opportunities. SSAC: Edinburgh. https://scottishscience.org.uk/publications/ssac-report-scotlands-critical-technologies-supercluster-challenges



1.8
Scotland's 2040 outlook

Scotland's 2040 outlook across the four pillars makes one point unambiguous: quantum is not a standalone industry; it is a multiplier that concentrates value in the supply chains Scotland already leads.

We estimate Scotland's 2040 gross value added (GVA) for four critical-technology pillars and the incremental uplift attributable to quantum (Fig.1.10). Sector baselines are anchored to the most credible available Scotland or UK evidence (e.g. Scotland photonics and digital-technology GVA and the UK semiconductor sector study), then projected to 2040 using bounded growth assumptions and market reports[15,16,17,18,19,20,21,22]

Quantum-linked uplift is estimated as additional value captured through quantum supply-chain demand and adoption, while explicitly avoiding double counting by separating pillar base activity from quantum-attributable increments. Uncertainty is quantified via Monte-Carlo simulation (10,000 runs) by sampling key parameters from tight, evidence-bounded distributions; results are reported as medians with P10–P90 error bars, representing the central 80% of model outcomes.

[15] Photonics Leadership Group (2025) UK Photonics 2025: The Hidden Economic Engine. PLG: Southampton. https://photonicsuk.org/wp-content/uploads/2025/06/UK_Photonics_2025_The_Hidden_Economic_Engine_online.pdf

[16] Scottish Government (2025) GDP Quarterly National Accounts: 2025 Quarter 2 (April to June). Scottish Government: Edinburgh. https://www.gov.scot/publications/gdp-quarterly-national-accounts-2025-q2/

[17] Department for Science, Innovation and Technology (2024) Semiconductor Sector Study. HM Government: London. https://www.gov.uk/government/publications/semiconductor-sector-study

[18] Scottish Science Advisory Council (2024) Scoping Agreement: Critical Technologies. SSAC: Edinburgh. https://scottishscience.org.uk/publications/ssac-scoping-agreement-critical-technologies

[19] Boston Consulting Group (2024) Quantum Computing On Track to Create Up to $850 Billion Value. BCG: Boston. https://www.bcg.com/press/18july2024-quantum-computing-create-up-to-850-billion-of-economic-value-2040

[20] ScotlandIS (2025) Scottish Technology Industry Survey 2025. ScotlandIS: Edinburgh. https://www.scotlandis.com/wp-content/uploads/2025/03/25-0331-Scottish-Technology-Industry-Survey-2025.pdf

[21] Scottish Government (2025) Scottish Annual Business Statistics 2023. Scottish Government: Edinburgh. https://www.gov.scot/publications/scottish-annual-business-statistics-2023/

[22] Office for National Statistics (2025) Regional gross value added (balanced) per head and income components. ONS: London. https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalregionalgrossvalueaddedbalancedperheadandincomecomponents/current

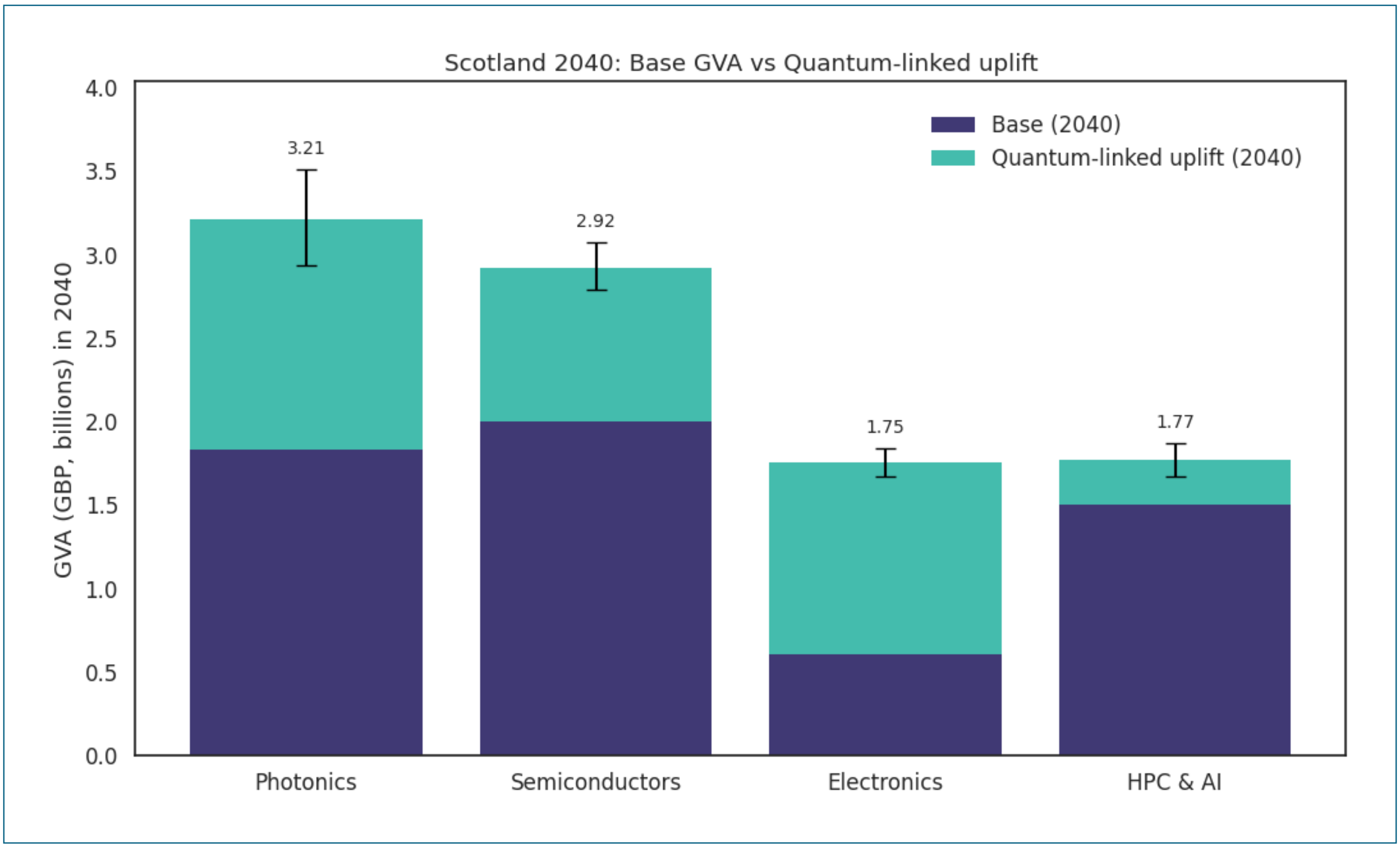


Fig. 1.10: Scotland's 2040 modelled quantum-enabled economic outlook across four pillars. The stacked bars show baseline gross value added alongside quantum-linked uplift, with uncertainty bands.

The structural base: photonics and semiconductors

As illustrated, photonics and semiconductors form the foundation of the quantum-enabled economy, capturing the largest absolute GVA. These sectors sit closest to the physical bottlenecks of deployment — high-performance lasers, defect control, and advanced packaging. Scotland's comparative advantage lies not just in hosting quantum firms, but in owning the enabling substrates that determine speed, yield, and reliability.

Specialisation in semiconductors.

Quantum hardware roadmaps are increasingly defined by semiconductor constraints: interconnect density, thermal budgets, and wafer-level packaging. Scotland does not need to dominate the global commodity market to succeed here. Instead, the strategy is to specialise in the high-value chain segments that quantum forces to improve — such as cryo-CMOS and RF front-ends — and export those capabilities to adjacent markets.

Electronics: the high-uplift layer

Quantum systems demand performance specs — ultra-low noise, precision timing, and cryogenic stability — that conventional markets rarely push. For Scotland, value capture will not come from commoditised volume, but from productising these "non-standard" control and instrumentation niches where performance is the primary differentiator.

HPC and AI: the connective tissue

The HPC and AI pillar is projected conservatively, acting as the connective tissue rather than a direct value pool. Quantum will not drive the broader AI economy in Scotland but will become indispensable for hybrid workflows, simulation, and error mitigation. Scotland's route to outsized GDP uplift involves treating quantum as a "demand shock" that upgrades existing critical technology supply chains. Policy must focus on reducing friction between these pillars, aligning roadmaps for packaging, metrology standards, and design toolchains.

1.9
Scotland's wider tech sentiment

From the ScotlandIS technology industry survey[19] of Scotland's tech sector, the message is clear: even outside the quantum community, there is appetite for deep-tech growth and the enabling conditions that quantum commercialisation (Figs. 1.11, 1.12) depends on — skills pathways, stronger collaboration and a more investable, internationally visible ecosystem.

The strategic takeaway is not that quantum is "smaller", it is that quantum is still being mentally filed as specialist deep tech by the wider tech base. That is an execution opportunity. If Scotland wants faster market capture, the job is to make quantum legible to non-quantum firms as an upgrade pathway they can sell into — through quantum-safe security and compliance needs, through hybrid quantum-classical workflows that sit naturally inside AI and data pipelines and through the productisation of enabling layers that digital firms already understand: tooling, verification, benchmarking and orchestration.

The encouraging part is cultural. Scotland's tech economy already values the connective tissue that quantum commercialisation requires: networks that move information fast, cluster-style convening and a strong bias towards collaboration and skills pipelines. ScotlandIS explicitly positions itself as a connector and a single voice to policymakers with active special interest groups and cross-industry links, which is exactly the kind of operating culture quantum needs to avoid fragmentation into isolated pilots.

Quantum is best treated as a demand shock that upgrades the supply chains Scotland already leads, especially photonics, semiconductors and enabling electronics. The lock-in window is early, because post-2030 growth will harden supplier relationships long before the market feels "fully mature". The practical end point is a single operating model that aligns packaging, metrology standards and design toolchains so delivery is repeatable and buyable.

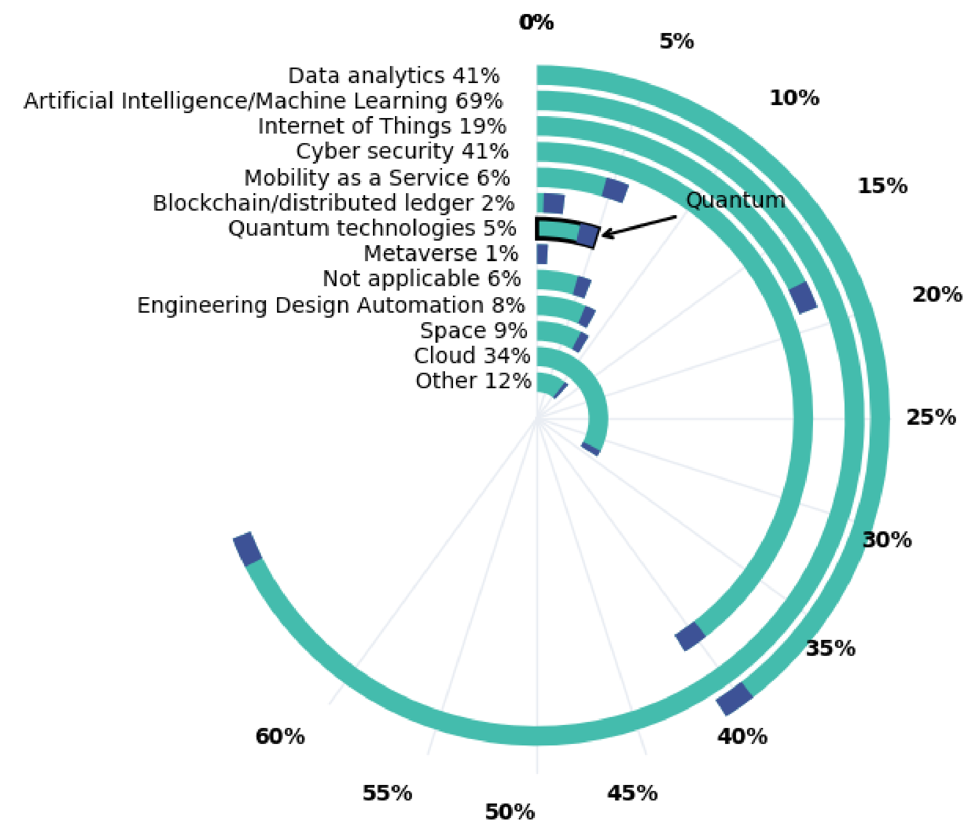


Fig. 1.11: Emerging opportunity signals in Scotland's digital tech sector, showing quantum as a recognised thread alongside dominant software-led growth themes.

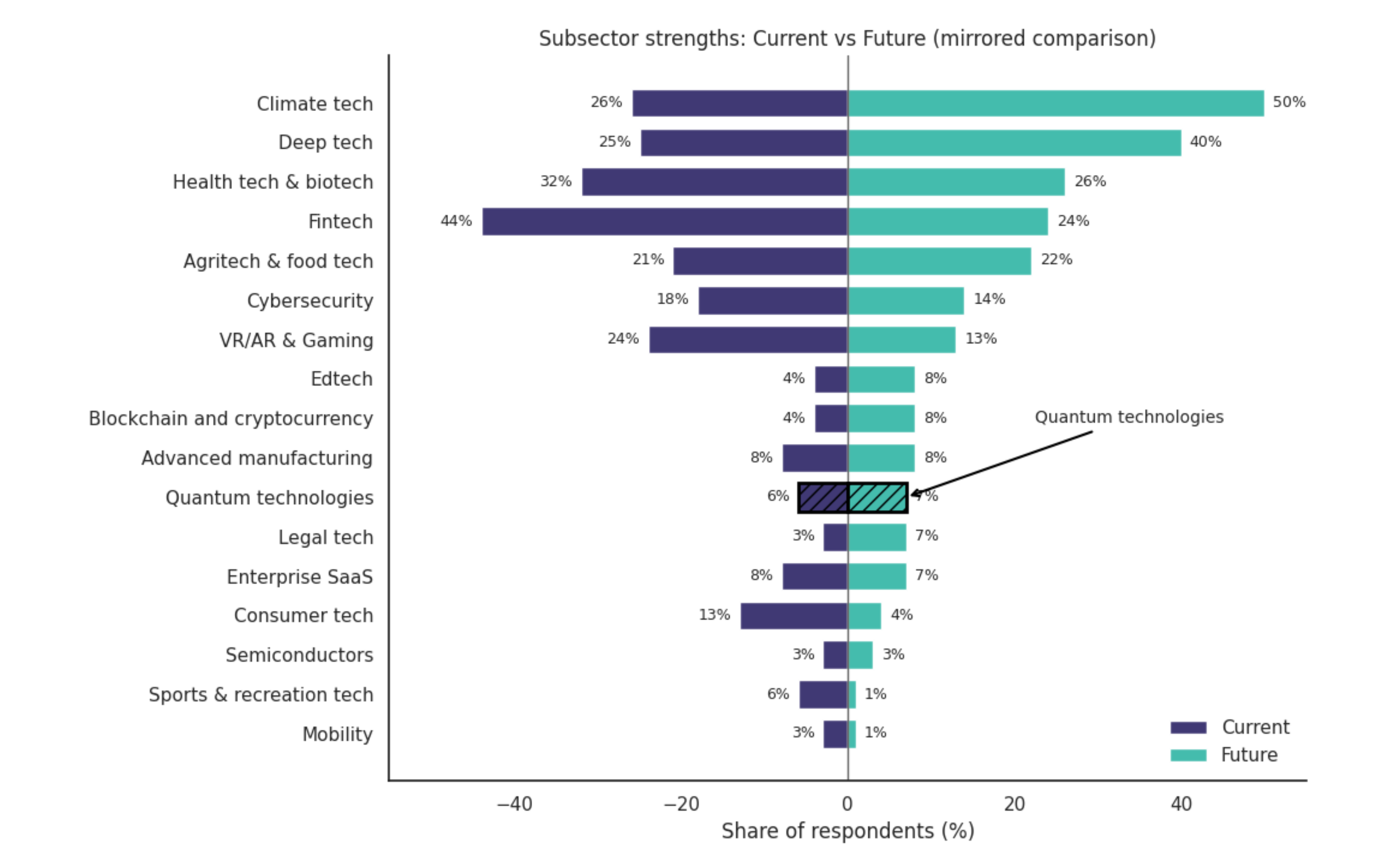


Fig. 1.12: Current versus future subsector strengths, illustrating how "deep tech" is expected to expand and how quantum should be positioned inside that growth narrative as an enabling, exportable capability.

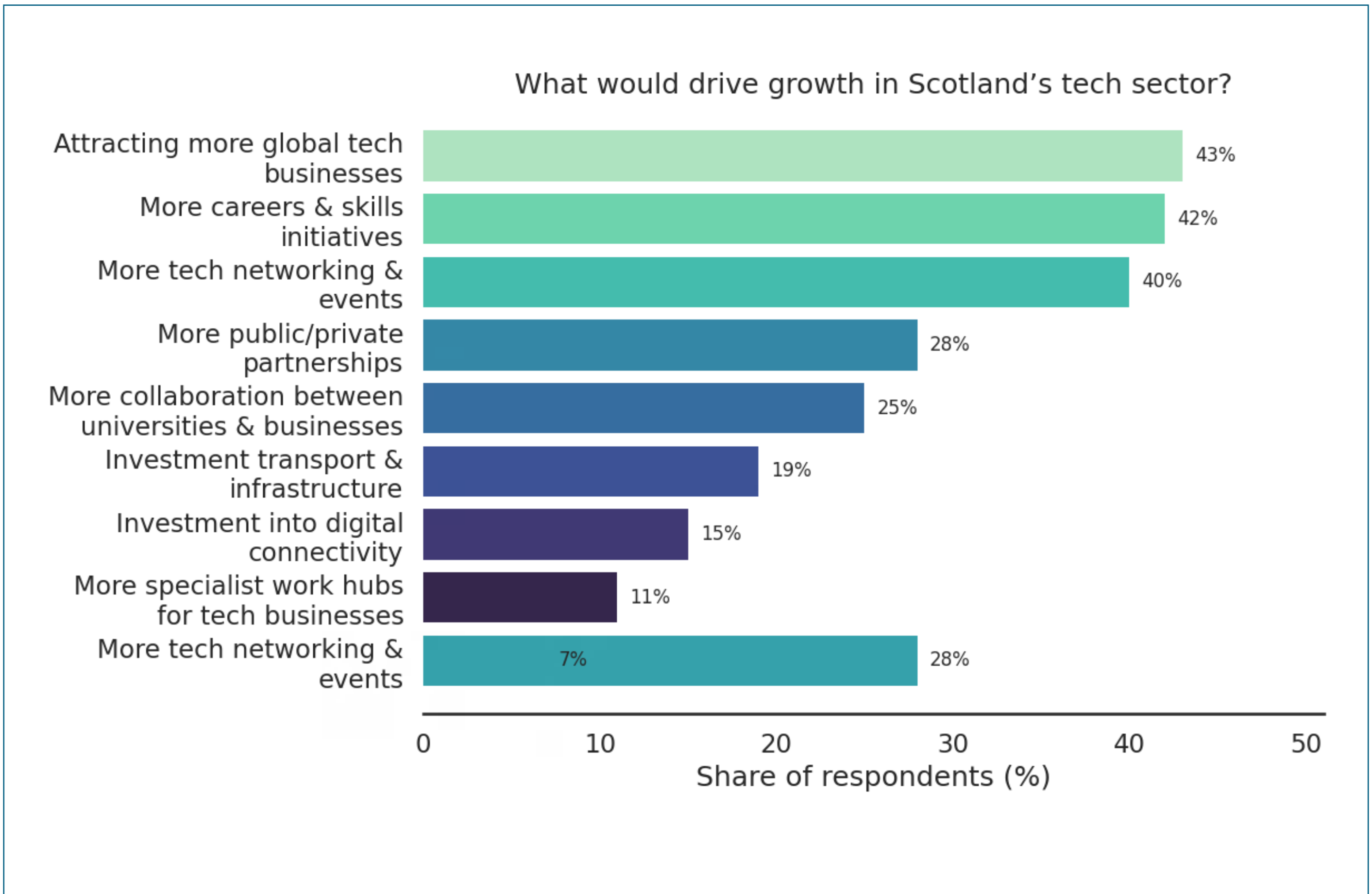


Fig. 1.13: What the Scottish tech sector says it needs to grow, a direct map onto quantum scale-up requirements: skills, partnerships and ecosystem connectivity.

Professor Gerald Buller
Director, Integrated Quantum Networks Hub

Scotland occupies an important place in the UK's quantum ecosystem thanks to our historic strengths in the photonics sector, and current leadership of two of the five national Quantum Technology Hubs. We have a key role to play in supporting the development of a national quantum skills base which can meet the fast-growing needs of the sector, especially given the dual-use nature of many quantum technologies under development.

Two key skills and talent challenges are a clear priority: addressing a critical shortage of non-specialist technical staff and improving interdisciplinary training while also strengthening engagement with adjacent sectors, for example cybersecurity, telecommunications, and space engineering technologies. The Quantum Technology Hubs, and the IQN via its leadership of the Quantum City outreach initiative, will play an essential role by promoting quantum literacy and awareness. Supported by additional EPSRC funding, we will be leading activities which highlight the value and importance of alternative career pathways through which non-quantum-specialists (including technical staff and apprentices) can participate in the growing UK quantum ecosystem.

Simultaneously, the organisation of cross-disciplinary events/workshops can help to educate and engage complementary sectors. This will be backed by funding for working with industry on internship/secondment schemes, joint projects and fellowships, and additional training programmes, aimed at educating and upskilling engineers, technicians, or business experts to support the emerging quantum economy. Together with partners like Quantum ARC, QURECA and our industry networks, we will continue to act as a key driving force in the UK's quantum talent pipeline.

Dr Steffan Gwyn

Business Development Manager
The UK Hub for Quantum-Enabled Position, Navigation, and Timing

The UK Hub for Quantum-Enabled Position, Navigation, and Timing (QEPNT) is one of the five National Quantum Technology Programme (NQTP) Hubs focused on delivering key quantum technologies to be developed into practical systems for resilient position, navigation, and timing (PNT) applications. Four of the Hub's partner universities are based in the central belt of Scotland, and we work with industrial partners that are critical to Scotland's quantum sector across the supply chain, from manufacturers to end users. Researchers from the Hub are translating their technology into industry through spinning out companies such as Photon Force, Singular Photonics, and Quantrologee, and supporting industry in Scotland's quantum sector through developing innovative solutions for quantum sensing systems.

To best support the adoption of quantum technology into real-world applications, it is imperative that there is strong buy-in from end users and government stakeholders. A strong industrial pull is hugely important to best understand key specifications that are required for quantum technology to meet, as well as ensuring interoperability with existing classical systems. QEPNT is supporting this by bringing the quantum community together with end users and government to ensure alignment. Scotland's expertise across a wide range of organisations will support the UK's drive towards sovereign capability in quantum technology, from nanofabrication to delivering full quantum-enabled solutions.

Glasgow is uniquely positioned to drive Scotland's significant contribution to the UK's Quantum Missions and the next leap in quantum technologies. Building on its strengths in advanced manufacturing, precision engineering, photonics, and cryogenics, Glasgow can establish the full infrastructure needed to accelerate progress in quantum hardware — including superconducting qubits and related systems.

CHAPTER

02

Commercialisation and adoption

Strategic valorisation of the Scottish quantum nucleus

Executive Summary

This chapter examines the commercial operating logic of Scotland's quantum ecosystem: how capability moves toward contracts, where value is being captured and where it is still at risk of leaking out.

Scotland's commercial quantum position is strongest when it is understood as a systems export economy, not a single-modality research story. The mapped landscape is led by quantum and enabling technology firms, with end users forming a smaller but highly valuable adoption and demand layer. That matters because it means Scotland already has the ingredients of a commercial cluster: suppliers, engineering capability, translational institutions and identifiable demand pathways. The task now is not to "build an ecosystem from scratch" but to convert an existing technical base into repeatable industrial outcomes.

A second key finding is that Scotland's commercial structure is asymmetric in a strategically useful way. The demand surface is broad across sectors, but adoption depth is concentrated in a smaller group of sectors where current quantum value is already legible. At the same time, the supply side is stronger in enabling and subsystem capability than in full-stack platform ownership. This should not be seen as a weakness, but the basis of a near-term export strategy. Scotland can capture value earlier by selling into global programmes through high-value components, integrated subsystems, validation capability and engineering-led deployment support.

- **Scotland's advantage is system-level, not single-firm.** The country's commercial strength comes from capability density and adjacency across research, enabling technologies, engineering and end users.
- **The demand base is broad enough to support growth.** The issue is not awareness, but rather the challenge of building the operating mechanisms that turn sector interest into procurement and repeat deployment.
- **The ecosystem's asymmetry creates an export opportunity.** Scotland's strongest near-term route is through enabling technologies, subsystems and deployment capability, not only end-platform ownership.
- **The main commercial bottleneck is scale-up, not invention.** Scotland is generating strong science, credible spin-outs and early market activity, but the highest risk still sits in the move from prototype to product. The weakest part of the pipeline is the scale-up layer: productisation and later-stage growth capital.
- **Scotland does not need to wait for the quantum market to fully mature to win.** The opportunity is there for Scotland to become the trusted place where global buyers source the enabling technologies, integrated subsystems and deployment-ready capability that make quantum work in the real world.

Findings	Implication	Scotland-specific mitigation
1. Bridging the engineering gap: from "prototype" to "product" Scottish firms excel at creating novel devices, but scaling requires transforming fragile lab units into rugged, manufacturable products.	**Global competitiveness:** Global primes do not buy experiments; they buy reliable subsystems. Mastering productisation (packaging, reliability, yield) opens the door to Tier-1 global supply chains.	**Build a national commercial offer for quantum-enabling hardware and subsystems** (photonics + electronics), with standard qualification evidence, clear delivery rou-tes and export-facing pac-kaging.
2. Scaling-up: from "venture capital" to "industrial capital" Investment landscape in Scotland remains heavily concentrated at the seed and series A stages. Standard VC models often struggle with the heavy infrastructure costs (CapEx) of deep tech. Hardware firms need a specific capital timeline to build factories and cleanrooms.	**Sovereign capability retention:** Ensuring high-growth firms have access to patient, asset-backed capital prevents them from leaving Scotland to find manufacturing funding elsewhere. It keeps the "factory" next to the "lab."	**A SNIB "hardware co-investment" thesis:** The Scottish National Investment Bank (SNIB) can shape a dedicated co-investment lane for quantum hardware, signalling to the market that Scotland supports the industrial scaling of its critical technologies, not just their invention.
3. Connecting Supply & Demand: from "technology push" to "mission pull" Scotland has broad sector interest (finance, energy, defence) but needs mechanisms to turn "interest" into "contracts."	**Market acceleration:** Actively directing this demand toward local suppliers creates a robust domestic market that validates technology for export. It turns "potential adopters" into "reference customers."	**Mission-led procurement:** Launch **"grand challenge" demonstrators** where the public sector acts as the anchor client (e.g.,"Quantum Sensors for Net Zero Grids"). This provides the commercial contracts that de-risk private investment and prove the technology works. Government should be the first procurer of the technologies.

2.

From capability to capital

Scotland's quantum opportunity will not be won by research output alone. It will be won by whether Scotland can convert a highly concentrated technical capability base into repeatable commercial products, anchor customers and exportable supply-chain positions. At an entity level, the mapped end-user base is broad and spread across multiple sectors, which tells us that quantum is already visible across the Scottish economy. But when the lens shifts from "who is present" to "where active commercial engagement is actually happening", the pattern becomes more concentrated. This industrial base is defined by a symbiotic tripartite structure: a nucleus of core quantum developers, a deep-rooted and world-leading enabling technology supply chain, and a nascent but rapidly maturing cohort of early-adopter end-users.

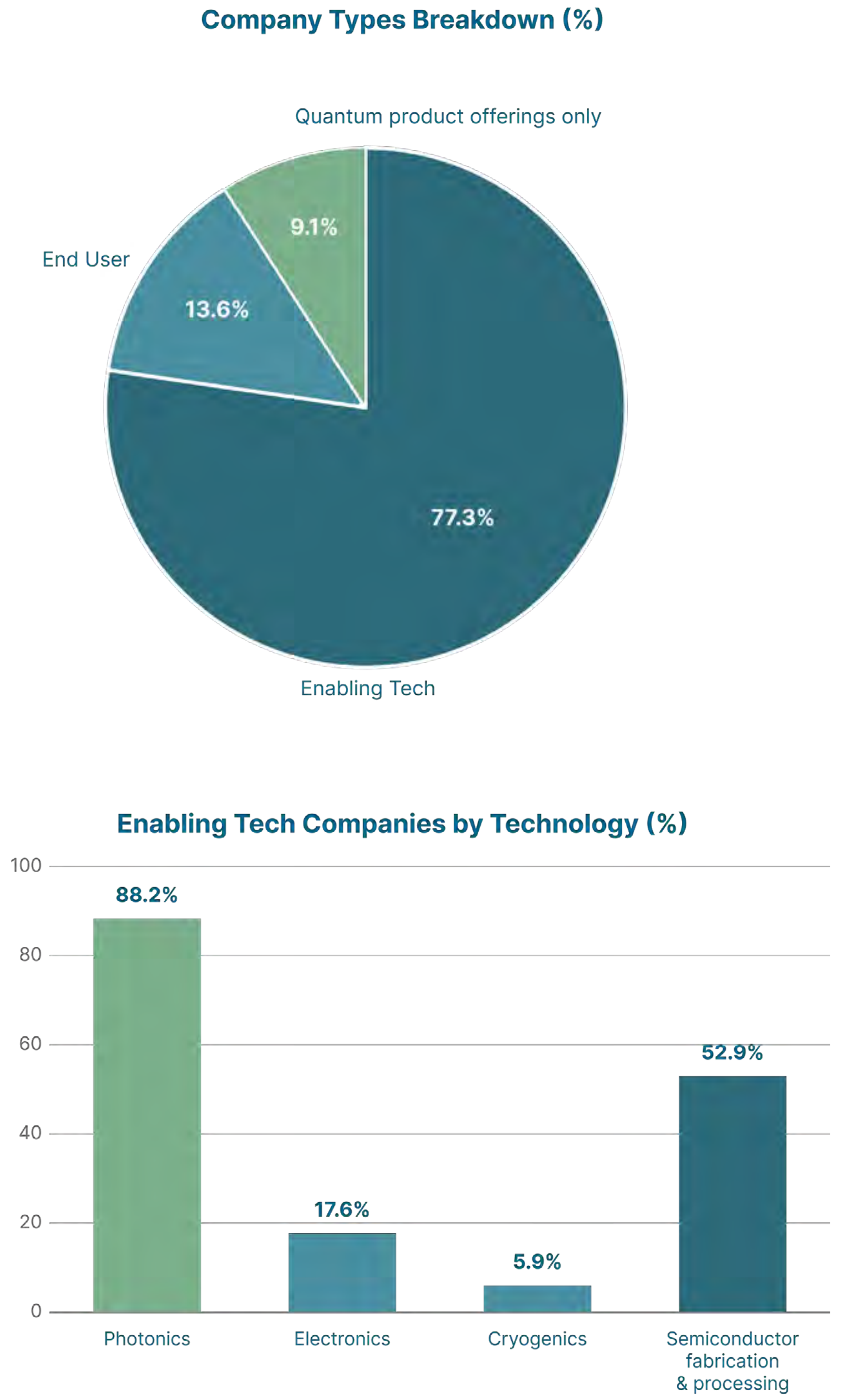


Fig. 2.1: (Top) Company type breakdown of Scottish quantum-related companies, showing a strong concentration of enabling technology firms. (Bottom) Technology profile of enabling quantum companies in Scotland, led by photonics and semiconductor fabrication and processing.

2.1
The supply-side

The company distribution plots show that Scotland's commercial quantum landscape is not primarily a "pure-play quantum startup" ecosystem. It is a layered industrial system led by enabling firms (Fig. 2.1, 2.2, 2.3). In the mapped company base, enabling technology companies account for 77% of the ecosystem, while core quantum product companies represent 9% and mapped end-users account for 14%. This matters because it means Scotland's strongest route to economic capture is not only through a few flagship quantum firms, but through a much broader base of enabling suppliers that can sell into multiple quantum modalities and multiple international markets.

This is not a sign of immaturity; rather, it is Scotland's primary competitive advantage. In a global market where the dominant qubit modality (superconducting, trapped ion, neutral atom) is still contested, the demand for enabling hardware, lasers, cryogenics, vacuum systems, and control electronics is universal and immediate.

The strongest layer is **photonics.** In the Glasgow–Strathclyde and Edinburgh–Lothians clusters, firms such as Vector Photonics, PowerPhotonic, Singular Photonics, Chromacity, Caledonian Photonics, Helia Photonics and others give the ecosystem real depth across lasers, optics and photonic devices.
What makes this strategically valuable is that these are not "nice to have" components, they are the physical building blocks of quantum systems and adjacent markets. For example, Vector Photonics is commercialising semiconductor surface-emitting lasers from University of Glasgow research, Singular Photonics is a fabless SPAD image sensor company with roots in the University of Edinburgh, and PowerPhotonic is focused on wafer-scale freeform optics and optical subsystems[23,24,25].

The second layer is the **electronics and quantum-hardware interface**, which is where the map gets especially interesting.

Quantcore[26] and Kelvin Quantum[27] show that Scotland is not only supplying optics, but also building the control and cryogenic hardware stack that quantum systems need to scale. Quantcore is positioned around niobium-based superconducting components and is linked to Glasgow's growing superconducting hardware effort, while Kelvin Quantum is explicitly focused on cryogenic electronics for quantum computers. Neuranics[28,29] adds another important dimension here: quantum-enabled magnetic sensing, custom integrated circuits and AI-enabled hardware/software, with strong Glasgow and Edinburgh university roots. This is exactly the kind of "photonics + electronics" convergence that gives a cluster long-term defensibility.

The third layer, and the one many ecosystems lack, is **fabrication and process infrastructure.** The map includes firms and facilities such as Helia Photonics[30], Kelvin Nanotechnology[31], III-V Epi and ALTER[32] which represent process capability, packaging, epitaxy, testing and scale-up pathways. This is strategically important because it reduces the gap between prototype and product. Helia brings thin-film optical coatings and integrated photonics manufacturing capability; Kelvin Nanotechnology is tied into the University of Glasgow and the James Watt Nanofabrication Centre; III-V Epi[33] provides III-V wafer foundry services (MBE/MOCVD and characterisation); and ALTER adds semiconductor testing, packaging and photonic capability for quantum and space applications.

Bridging the gap between industry and academia, a separate differentiator is QURECA[34]. While many clusters focus only on hardware, QURECA supports the parts that help an ecosystem grow and translate, including talent, education, strategy, recruitment and commercialisation.

[23] Vector Photonics (n.d.) *A Revolution in Laser Technology*. https://www.vectorphotonics.co.uk/

[24] Singular Photonics (n.d.) *About*. https://singularphotonics.com/about/

[25] PowerPhotonic (n.d.) *Company Overview*. https://www.powerphotonic.com/

[26] Quantcore (n.d.) *Product*. https://quantcore.co.uk/product/

[27] Kelvin Quantum (n.d.) *Solutions*. https://www.kelvinquantum.com/

[28] Neuranics (n.d.) *Pioneering Magnetic Sensing Solutions*. https://neuranics.com/

[29] Neuranics (2025) *Neuranics to Establish World-Leading Semiconductor Facility Backed by Glasgow's £160M Investment Zone*. https://neuranics.com/news/neuranics-investment-zone/

[30] Helia Photonics (n.d.) *Company Overview*. https://heliaphotonics.com/

[31] University of Glasgow (n.d.) *Kelvin Nanotechnology*. https://www.gla.ac.uk/explore/glasgowinnovationdistrict/innovationandentrepreneurship/kelvinnanotechnology/

[32] ALTER Technology Group (n.d.) *About Us*. TÜV NORD. https://www.altertechnology-group.com/en/about-us/

[33] III-V Epi (n.d.) *Novel III-V Epitaxial Structures for Small Volume Manufacturing and Research and Development*. https://www.iii-vepi.com/

[34] QURECA (2024) *Member Spotlight: QURECA*. Technology Scotland. https://www.qureca.com/ and https://technologyscotland.scot/member-spotlight-qureca/

Scotland Quantum Industry Map

Regional Clusters of Companies and End Users

Glasgow and Strathclyde
Tayside, Central and Fife
Edinburgh and Lothians

— — — — Non exhaustive list of companies with at-least 1 core product offering/enabling/ active project in quantum technologies

— · · — End-users/ adopters of quantum technologies.

★ Note: Certain end-user organisations also maintain active quantum R&D and/or commercial offerings and have therefore been included within the Companies category for this map.

Craft Prospect[35] is an important inclusion because it shows how Scotland's quantum base can extend into **space applications.** Its presence on the map points to a credible route from core hardware capability into downstream systems such as space-based quantum communications and QKD.

2.2
Cluster branding

Scotland's quantum advantage is not only technical, but also strategic and recognisable to the outside world. The Glentanglement®[36] brand, created by Fraunhofer UK and managed by Technology Scotland, gives the ecosystem a clear international identity as "Scotland's Quantum Valley".

By linking Silicon Glen's manufacturing legacy with quantum entanglement, the brand signals both industrial depth and future ambition.

More importantly, it acts as a coordination tool: it brings firms and universities under one recognisable banner, creates a single front door for investors and partners and strengthens Scotland's ability to convert collaboration strength into commercial contracts and inward investment.

[35] Craft Prospect (n.d.) *Small Satellite Company*. https://www.craftprospect.com/

[36] Technology Scotland (2024) *Glentanglement® Directory*. https://technologyscotland.scot/wp-content/uploads/2024/11/Glentanglement-directory.pdf

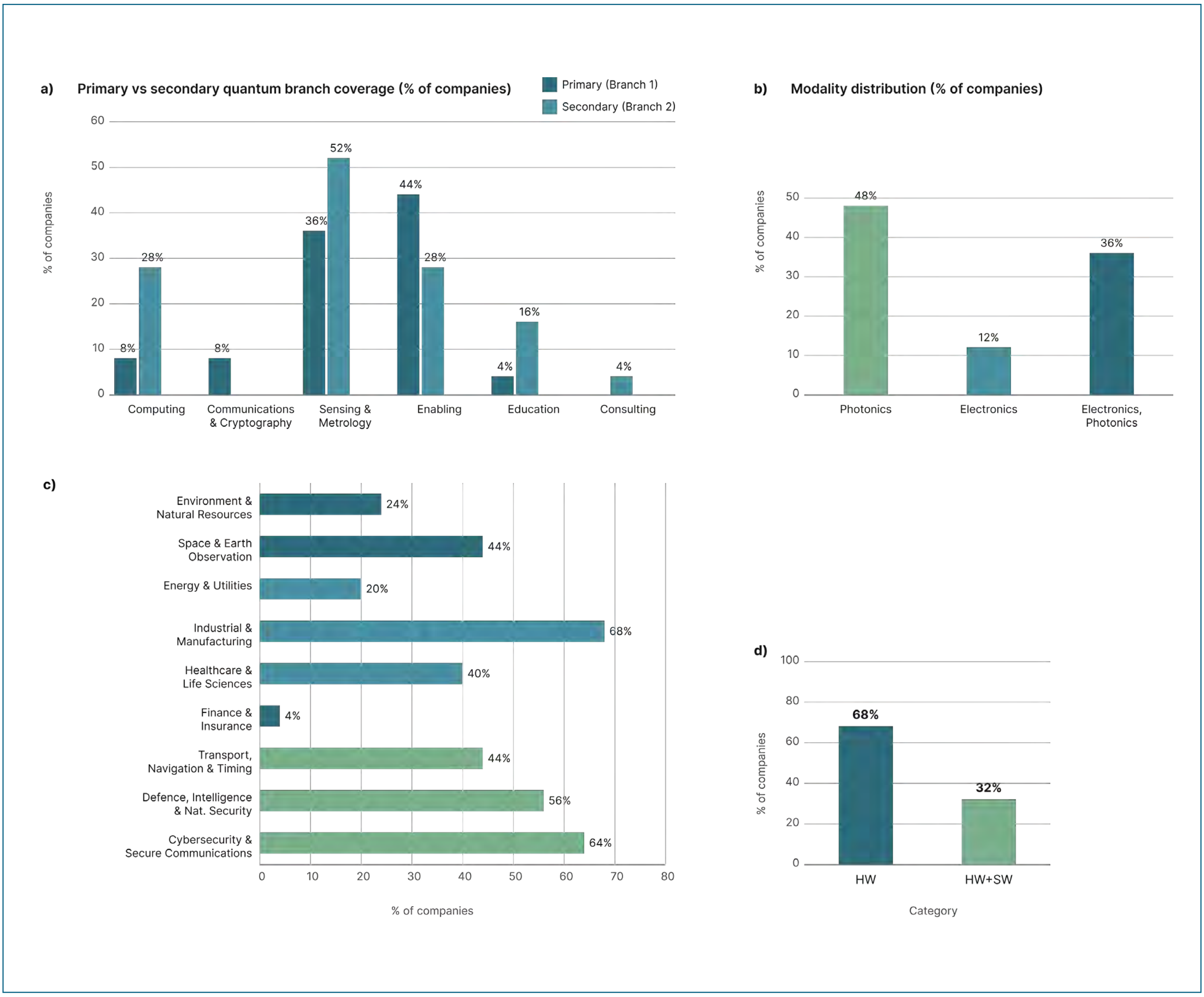
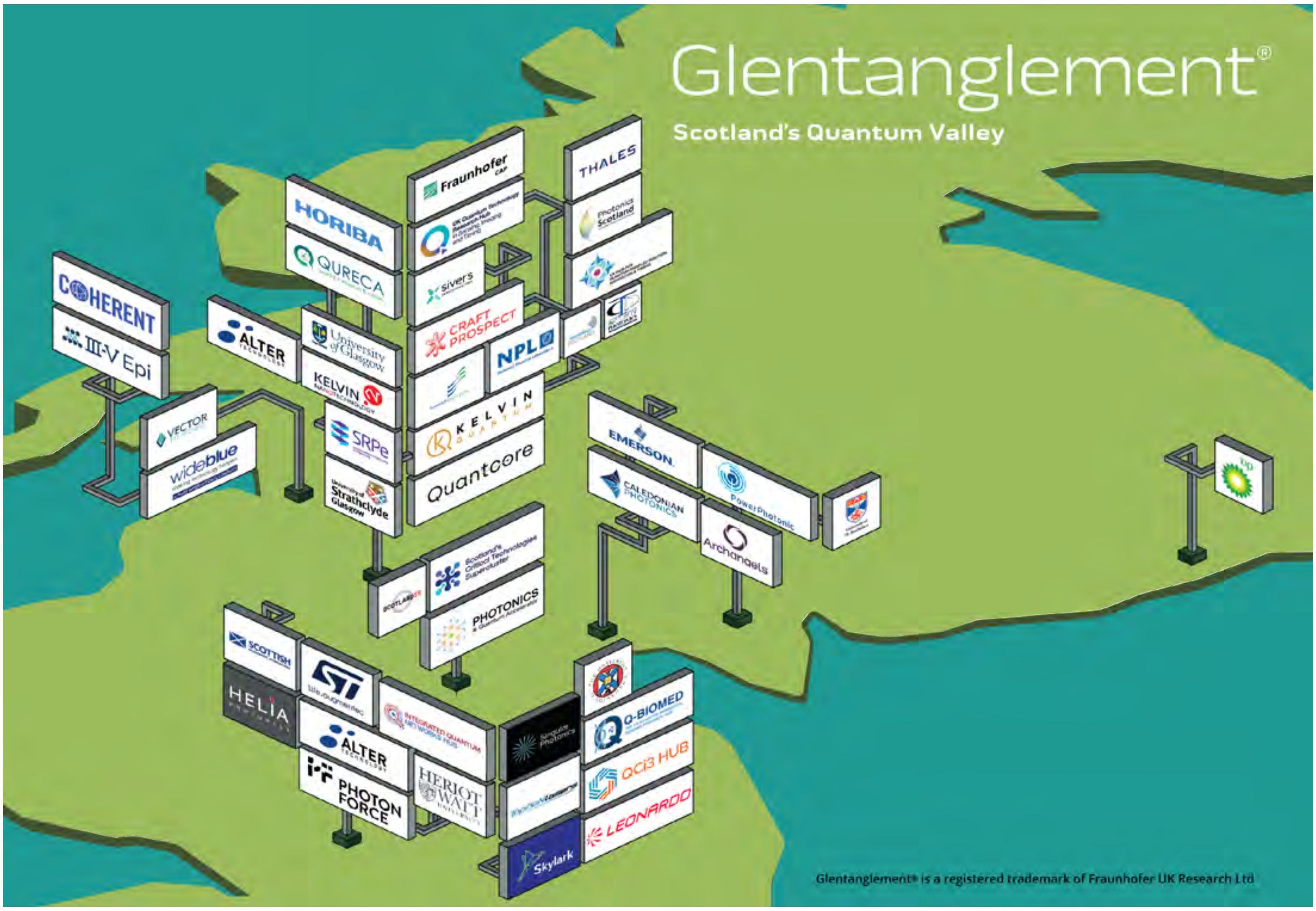


Fig. 2.3: Overview of the Scottish quantum supplier ecosystem: (a) primary and secondary quantum use-case/application branch coverage, (b) modality distribution, (c) end-sector coverage and (d) company technology profile by implementation type, showing a predominantly hardware-led supplier base with a smaller hybrid hardware-software segment. Taken together, this suggests Scotland's near-term advantage lies in scaling as a high-value enabling and integration supply base, while the main strategic gap is in downstream software, integrator and application-layer translation capacity.



(Image: Fraunhofer)

2.3
End-user ecosystems

End-user mapping should not be interpreted as a proxy for industrial weight. It is better understood as a map of where demand signals are emerging.

In Scotland, those demand signals are broad. Financial services is currently the strongest visible adopter base and defence, aerospace and security form the second major demand anchor (Fig. 2.4). The underlying logic is straightforward: these sectors already operate with high-value optimisation problems, security-sensitive data, timing requirements and procurement environments that reward performance gains. That makes them early quantum adopters even before large-scale quantum computing maturity.

Scotland's quantum supply base is hardware-led while current end-user demand is more software-led, especially in optimisation, modelling and cybersecurity. That gap is strategic, not a weakness, but it means Scotland needs stronger translation layers such as systems integration, software interfaces, benchmarking and solution design to connect hardware capability to real end-user demand.

This distinction matters because it changes what policy should optimise for. If policymakers read the market as simply "end-user heavy" they may over-prioritise awareness and pilots. If they read it correctly, they will focus on the conversion interfaces between a broad demand surface and a smaller but strategically critical supply core.

End-sector adopter categories	Priority application area
Financial Services	Portfolio optimisation and fraud detection.
Defence, Intelligence & Security	Secure comms and GPS-independent navigation.
Energy & Utilities	Grid synchronisation and subsurface monitoring.
Healthcare & Life Sciences	Drug discovery and non-invasive medical imaging.
Transport, Navigation & Timing	Autonomous vehicle control and precision timing.

Table 2.1: End-sector use-cases

Second, the modality distribution in end-user activity is concentrated across sensing and timing use cases, communications/cryptography and computing. This is strategically significant. It means the market is not waiting for fault-tolerant quantum computing to generate demand. Buyers are already moving where performance and risk reduction are legible today: sensing, timing and secure communications. This aligns well with Scotland's hardware strengths and should be treated as a near-term commercial priority, not a secondary pillar.

Strategic implication: Scotland's immediate commercial play is not "all sectors at once". It is to use finance and defence/security as anchor markets while

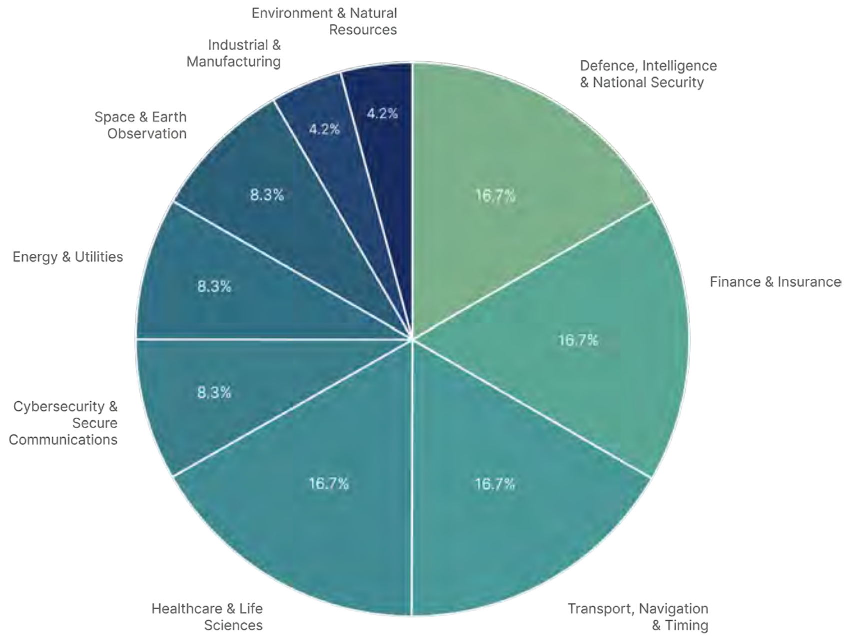


Fig. 2.4: Sector distribution of Scottish quantum end-user organisations across key application domains.

building export-ready propositions in sensing, timing and secure networking for broader sectors.

2.4
The supply-demand disconnect

The sector alignment plot shows that supplier capability coverage is broader than current domestic end-user adoption in several sectors (Fig. 2.5). In practical terms, Scotland has already built technical capacity that exceeds what the domestic market is currently absorbing. That is a good problem to have, but only if it is managed deliberately.

This creates two strategic pathways:

1. **Domestic demand shaping**

Scotland can increase local absorption by using public procurement, mission-led demonstrators and coordinated industry challenge calls to create reference customers.

This matters because early quantum sales are evidence driven. A supplier that can point to a live deployment in Scottish energy infrastructure, public security or industrial monitoring has a far stronger export proposition than one with only a lab demonstration.

2. **Export-first subsystem strategy**

Scotland can also treat the capability surplus as an export engine. The enabling base is already broad enough to support international programmes in quantum sensing, networking, and photonic components. As this chapter should make clear, domestic adoption is necessary for credibility, but export revenue is where the scale will come from. The role of domestic demand is to reduce sales friction and increase global trust, not to absorb the entire output of the ecosystem.

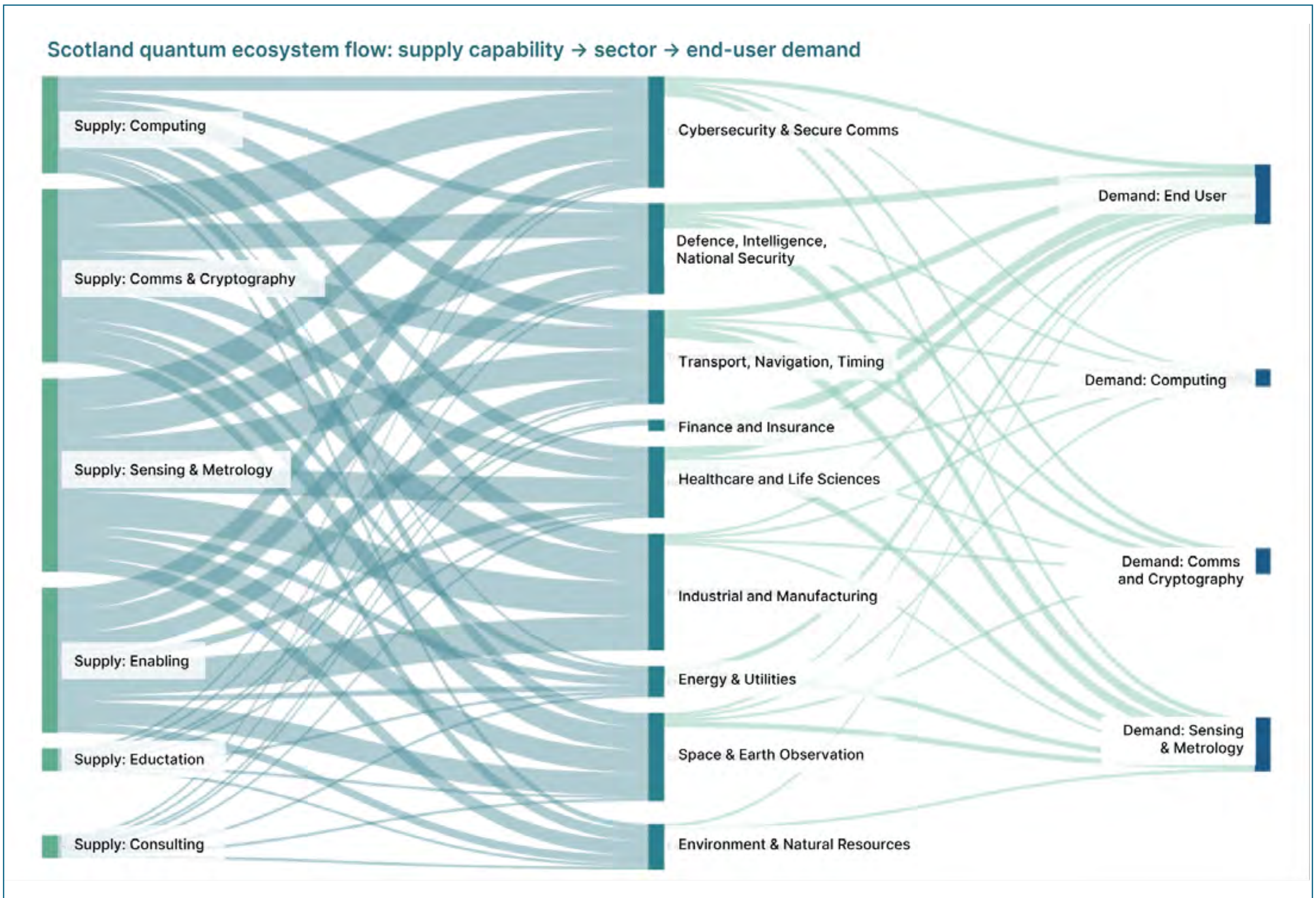


Fig. 2.5: Sankey map of Scotland's quantum ecosystem flows, linking supplier capabilities (left; computing, communications, sensing, enabling and support functions) to use-case sectors (centre) and observed end-user demand signals (right). The flow widths represent the relative concentration of company tagging across each connection, showing where supply capability is already dense (especially enabling and sensing routes across industrial, cybersecurity, defence and transport sectors) and where domestic end-user pull is narrower or more selective. This figure highlights the strategic imbalance discussed in this section 2.3: Scotland has built broad upstream capability, but demand absorption is concentrated in fewer downstream pathways, creating both a domestic demand-shaping opportunity and an export-led subsystem growth opportunity.

2.5
Capturing value through coordination

Scotland already has a strong commercialisation architecture, with credible capability across universities, translational centres, accelerators, cluster organisations, public funders and end-user validators. The next strategic step is to strengthen coordination through a clear cross-communication mechanism, so these actors operate as one connected pathway for founders, investors and customers.

Who does what in the commercial conversion chain:

- **IP generation and venture formation (universities and TTOs)**

The Universities of Glasgow, Strathclyde, Edinburgh and Heriot-Watt remain the principal source of quantum IP and founding talent. Their commercialisation entities and related university structures are the front end of the pipeline, converting research outputs into patents, licensing opportunities and spin-outs. In quantum specifically, Glasgow has already highlighted companies such as Quantcore[37] and Kelvin Quantum[38] as examples of technologies being moved toward products and services through programs like InfinityG and Critical technologies Accelerator (CTA). At Edinburgh, this front end is more visibly institutionalised through Edinburgh Innovations, which is the University of Edinburgh's dedicated commercialisation service.

[37] University of Glasgow (2026) *Quantcore Raises £2.5m to Build UK's Sovereign Manufacturing Capability.* https://www.gla.ac.uk/news/headline_1248072_en.html

[38] Kelvin Quantum (2025) *Kelvin Quantum Joins ChipStart UK Incubator.* https://www.kelvinquantum.com/news/blog-chipstart

- **Applied translation and de-risking (RTOs, hubs and applied centres)**

Fraunhofer CAP, CENSIS[39] and the national quantum hubs are not simply "support organisations". They are the de-risking layer. They reduce technical uncertainty, help firms prototype in an industrial context and connect academic capability to sector needs. This is where a lot of real commercial value is created before formal revenue appears. They should be thought of as valorisation actors, not background institutions.

- **Commercial readiness and venture acceleration**

The Photonics & Quantum Accelerator[40] (PQA) is especially important because it addresses a common failure point in deep tech: teams are often technically excellent but commercially underprepared. PQA's role in small translational grants, coaching and business training is precisely the kind of intervention that improves survival rates in hardware spin-outs. This should be framed as "commercial throughput infrastructure", not just another funding programme. The call structure also reinforces this. PQA funding categories include mobility/secondments, commercialisation and entrepreneurship, and partnership development.

Quantum ARC[41] (the Scottish Research Alliance for

[39] Research Innovation Scotland (n.d.) *CENSIS.* https://www.research-innovation-scotland.co.uk/member-organisations/

[40] Photonics & Quantum Accelerator (n.d.) *Programme Overview.* https://photonicsaccelerator.ac.uk/

[41] Quantum Technologies Alliance for Research Challenges (n.d.) *Overview.* https://quantum-tech-alliance.co.uk/

Fig. 2.6: Overview of Scotland's key valorisation organisations supporting quantum technology development, commercialisation and adoption, including cluster bodies, accelerators, enterprise agencies and sector networks.

Fig. 2.7: Quantum ARC kick-off event (Feb 2024) (Image: Quantum ARC)

Challenges in Quantum Technologies) is an SFC-funded national network that connects academia, industry, end-users and wider society to build quantum collaborations around real-world challenges in Scotland. It acts as a coordination and capability-building layer by supporting cross-sector projects, skills development and funding pipelines that help translate quantum research into applications.

- **Cluster orchestration and international visibility**

Technology Scotland's role is more strategic than a normal trade body role. It is the natural candidate to operate cluster coordination, market signalling and the "single front door" function for external investors and new companies and is the facilitator for the critical technologies' supercluster[42]. What is missing is a formal mandate, stable resource, and a shared operating model with agencies and universities.

- **Capital allocation (public agencies, mission bank and private investors)**

Scottish Enterprise, UKRI and the Scottish National Investment Bank (SNIB) form the backbone of early and mid-stage de-risking capital. Local angels and VCs then support selected firms into seed and Series A stages. This is a real capital stack, but it remains thinner than what a hardware-led sector needs for repeated scale-up cycles.

- **Demand validation (anchor end-users and public sector buyers)**

Financial institutions, defence actors and telecom operators are not peripheral to commercialisation. They are part of the valorisation system because they create the evidence base that makes private investment and export sales possible. End-users should be thought of as co-developers and validators, not just "adopters".

Strategic implication: Scotland's challenge is now orchestration. Valorisation actors exist. The task is to make them behave like one commercial pathway.

[42] Technology Scotland (2024) *New Initiative Launched to Build £10bn Critical Technologies Supercluster in Scotland.* https://technologyscotland.scot/new-initiative-launched-to-build-10bn-critical-technologies-supercluster-in-scotland/

Fig. 2.8: PQA steering committee: Prof. Andy Harvey (Principal Investigator), Prof. Derryck Reid (Co-I for Heriot-Watt University), Prof. Erling Riis (Deputy Co-I for University of Strathclyde), Dr Richard Mosses (Project Manager) and Prof. Christopher Leburn (Technology Exploitation Director) (Image: Photonics and Quantum Accelerator).

2.6

The "scale-up cliff"

While the public sector has provided a robust safety net, the private investment landscape in Scotland remains **heavily concentrated at the Seed and Series A stages.** Active local angel syndicates like Equity Gap and VCs like Eos Advisory and Kelvin Capital have provided the initial fuel for firms like Vector Photonics and Chromacity. However, the cluster faces a significant hurdle when moving toward Series B and beyond, where the capital requirements for high-volume manufacturing and international expansion often exceed the capacity of local funds.

The administration of M Squared Lasers on 27th August 2025 is a cautionary episode for Scotland's photonics and quantum ecosystem. M Squared was an award-winning Glasgow-based photonics and quantum technology company, and the first major investment made by the Scottish National Investment Bank, which later confirmed total exposure of £34 million across multiple tranches. Interpath attributed the collapse of the company to a combination of macroeconomic pressures, component scarcity, a tightening skills market and reduced orders from some customers.

Fig. 2.9: Scotland's Critical Technologies Supercluster reception event (Mar 2025) (Images: Technology Scotland).

M Squared's intellectual property and certain assets were subsequently acquired out of administration by Novacene Photonics Ltd, a newly incorporated Glasgow-registered company. In strategic terms, this is best understood as an IP and capability retention **event** for the ecosystem, preserving key assets and technical continuity in Scotland even after the original company's dissolution[43,44].

This case study highlights that substantial capital injection is a necessary but insufficient condition for success; it must be coupled with resilient supply chains and "proxy prime procurement" that guarantees an early customer base.

Hardware quantum companies face a deeper valley of death than most software ventures: they are capital-intensive, slow to qualify and highly exposed to component and supply-chain risk. As a result, they rarely fit standard venture timelines unless they are supported by strong co-investment, early customer validation and a credible path from prototype to productisation.

What this means for funders and policymakers

- **For Scottish Enterprise**: continue early-stage catalytic instruments, but tie more support to productisation milestones and customer validation pathways.
- **For SNIB**[45]: the opportunity is not only individual company investment but shaping a national co-investment thesis around quantum-enabling hardware and integrated subsystems.
- **For private investors**: Scotland needs a clearer investor proposition that explains why quantum hardware here is not "science risk" alone, but investable industrial capability with cross-sector demand.
- **For government**: fundability improves when the state reduces non-financial risk through infrastructure access, standards and early procurement. Create a dedicated scale-up capital lane for quantum hardware.

[43] Photonics Spectra (2026) *M Squared Lasers Completes Sale of Assets.* https://www.photonics.com/Articles/M-Squared-Lasers-Completes-Sale-of-Assets/a71642

[44] The Herald (2026) *Sale of Assets from Glasgow's M Squared Lasers Completed.* https://www.heraldscotland.com/news/25609498.new-glasgow-firm-acquires-assets-m-squared-lasers/

[45] Scottish Parliament (2025) 'Scottish National Investment Bank', Public Audit Committee: Official Report, 10 September. https://www.parliament.scot/chamber-and-committees/official-report/search-what-was-said-in-parliament/PA-10-09-2025?iob=141452&meeting=16570

Scotland's commercial quantum opportunity is not hypothetical, and it is not waiting for a distant "quantum future". It is already visible in the structure of the mapped ecosystem and targeting the near-term enabling layers.

The commercial message is clear: Scotland has a credible industrial base, a distinctive components advantage and the institutional ingredients to lead. What it needs now is tighter orchestration across the translation layer, stronger support for hardware productisation and a more deliberate conversion of broad sector interest into concentrated adoption.

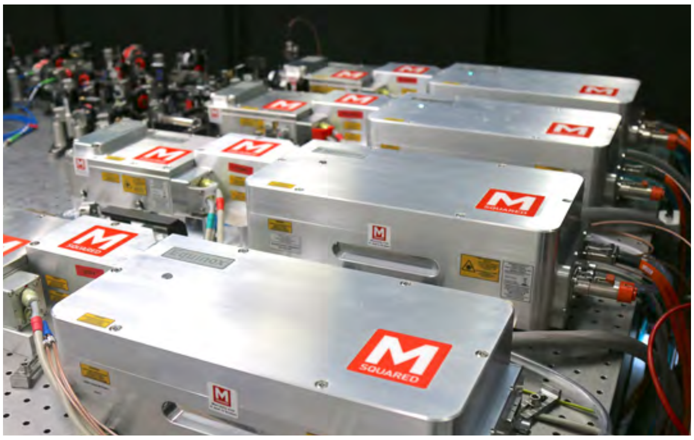


Fig. 2.10: M Squared Lasers entered administration August 2025.

Funding body / investor	Programme / type	Funding type	Typical size
Public & Agency			
Scottish Enterprise	SMART: SCOTLAND	Grant	Up to £100k
Scottish Enterprise	New to Equity Pilot	Convertible Loan Note	£250k – £750k
Scottish Enterprise	Equity Investment	Equity	Variable
UKRI (Innovate UK)	ISCF / Quantum Missions	Collaborative R&D Grant	£500k – £5M+
Scottish National Investment Bank	Mission-led Investment	Equity / Debt	£1M – £50M+
Photonics & Quantum Accelerator (PQA)	Impact Acceleration	Grant	£5k – £150k
Private			
PXN ventures	Venture Capital	Equity	Series A
Eos Advisory	Venture Capital	Equity	Seed / Series A
Kelvin Capital	Venture Capital	Equity	Seed / Series A
Equity Gap	Angel Syndicate	Equity	Seed
Foresight Group / WAE	Venture Capital	Equity	Series A
Capital for Colleagues	Venture Capital	Equity	Seed / Series A
STL Tech	Venture builder	Equity / venture support	Pre-seed / Seed
Quantum Exponential	Venture Capital	Equity	Seed / Series A / Series B

Table 2.2: Key Public and Private Funding Instruments for Scottish quantum ventures.

Simon Andrews

Executive Director,
Fraunhofer UK Research Ltd

The projects we are involved with, and our mission, is very much about making sure things don't stall between lab and prototype. In the exciting but nascent Quantum Technologies space, many technologies are still at the stage of making first demonstrations, so we are often using the best available packaging to just make it happen and prove the point, de-risk that the system is achievable. That maybe arrives with compromise on the cost for a one-off, and often size. I think the key process is heterogenous integration, and we agree with the RAEng report's discussion of that topic. We work with our close colleague Prof Michael Strain at Strathclyde, have an interest in its IP, and fully expect this to be a key enabler.

Dr Jack Brennan

Founder and Chief Executive Officer, Quantcore

There is a huge amount of innovative, potentially marketable research being carried out by PhDs and postdocs throughout Scotland, particularly in quantum. While it's important to remember that not every researcher wants to start a business and take their research to market, those who do must be supported and enabled. Teaching on key aspects of this process, IP protection, market validation, pitching etc. are essential. What is also essential is the need to help the potential entrepreneur develop business plans, financial models, go to market strategies among many others. While teaching on these subjects is also very useful, there must also be examples provided to help overcome one of the biggest barriers to researchers becoming entrepreneurs: simply not knowing where to begin and what will be required.

Similarly, a key component to any strategy to help researchers take their innovations out of the lab, must provide strong mentorship. It is invaluable to have time and space to discuss ideas at length with someone who has experience, is good at explaining, and who has a positive outlook.

CHAPTER

03

Testbeds & infrastructure

The physical and digital foundation of Scotland's quantum ecosystem

Fig 3.1: Image of Scotland etched in silicon wafer created by the University of Glasgow and Kelvin Nanotechnology to celebrate Glasgow's 850th anniversary (Image: University of Glasgow).

Executive Summary

Scotland has cultivated a uniquely comprehensive and geographically concentrated portfolio of infrastructure for quantum technologies. This integrated ecosystem represents a significant national asset, providing a coherent pathway from fundamental research and materials science through to component fabrication, systems integration, and full-scale field demonstration. This 'full-stack' capability, encompassing a world-class fabrication core, a deep and mature enabling technology supply chain, a diverse set of application-specific testbeds, and a national high-performance computing backbone, is a primary driver of the nation's competitive advantage in the global quantum race.

The analysis presented in this chapter details the constituent elements of this infrastructure, mapping their capabilities and roles within the quantum technology value chain. It identifies four principal pillars:

1. **The fabrication core:** A network of university-led and commercial foundries providing the foundational capability to manufacture quantum and quantum-enabling devices from raw materials, covering Technology Readiness Levels (TRLs) from 3 to 9.
2. **The enabling supply chain:** A dense cluster of companies, many with global leadership positions, providing the critical components, lasers, optics, control electronics, and packaging services required to build functional quantum systems.
3. **The proving grounds:** A suite of application-specific testbeds and validation facilities that allow quantum technologies to be tested and de-risked in environments representative of their final use, including space, telecommunications networks, energy grids, and autonomous systems.
4. **The digital backbone:** A national high-performance computing (HPC) capability, essential for the simulation, design, and optimisation of quantum hardware and algorithms, and for processing the complex data generated by quantum experiments.

The co-location of these pillars, particularly within Scotland's Central Belt, creates a powerful, synergistic environment that accelerates innovation cycles and lowers the barriers to commercialisation.

Findings	Implication	Scotland-specific mitigation
Scotland's edge is infrastructure density that behaves like a single conversion engine, compressing the design–simulate–build–test loop rather than scattering capability across sites.	This is how Scotland can win on repeatability and integration, not just discovery. If it is not made "buyable", global programmes will still source subsystems elsewhere and Scotland becomes a high-leakage R&D node.	Invest more in infrastructure for global sovereignty and leadership. Turn the conversion engine into a national product: standard qualification evidence, shared metrology expectations and clear service throughput so buyers can procure Scottish photonics and electronics as qualified subsystems, not one-off projects.
The bottleneck is productisation: Packaging, Assembly, Integration and Test (PAIT) is uneven across modalities and the mid-TRL path is slowed by fragmented routes.	Mid-TRL work will default to easier pathways outside Scotland, taking IP, learning curves and first purchase orders with it.	Treat shared PAIT as national infrastructure that serves both photonics and electronics equally, with common reliability and acceptance testing routes that keep scale-up gravity in Scotland.
There is no single trusted live database showing what assets exist, current availability and access terms, which blocks resource-sharing and collaboration at pace.	Scotland pays an "internal friction tax": SMEs and researchers waste time navigating access and collaborations form slower than international competitors.	Build a Scotland-wide infrastructure register plus standardised access (pricing, booking, IP and collaboration routes) so capacity can be shared and pulled into bids quickly
The hard constraint is human throughput: specialist technicians and engineers are as strategic as the hardware (cleanroom, RF, vacuum and cryogenics).	Without a skills pipeline, infrastructure advantage stalls and upgrade cycles slow, even if capex exists.	Fund an infrastructure-linked skills pipeline with training tied to the actual operational stack, so scaling is limited by throughput and demand, not people.

3

The importance of infrastructure

Quantum does not scale on ideas alone; it scales on access to repeatable fabrication, packaging that survives the real world, qualification that buyers trust, and compute that tightens the design–build–test loop. Scotland's edge is that these capabilities already exist as a dense, connected system rather than scattered assets, which is why infrastructure is not "supporting context" here; it is the conversion engine for economic capture.

3.1

Scotland's quantum conversion stack

If Scotland's quantum advantage is framed solely through the lens of research excellence, the benchmark remains academic prestige. However, **economic capture**, the ability to anchor value and industry within a territory, is not decided in the laboratory. It is decided where prototypes become repeatable products, where packaging survives field conditions, and where iteration cycles are compressed to fit within a commercial envelope.

Scotland's differentiator is a compact, end-to-end infrastructure system designed to function as a conversion engine, moving quantum capability into market-ready assets (Fig. 3.2).

Scotland's quantum infrastructure serves as a cohesive "conversion engine," transforming high-level research into market-ready industrial assets through a series of integrated stages. This process begins with Scotland's university-operated fabrication facilities (**fabrication core**), where a local design–fabricate–test loop keeps iteration and know-how in one place so each build directly improves the next, cutting the time and cost required to reach a functional device.

To navigate the volatile transition from academic prototyping to industrial production, there is strategic provision for **local translational routes**, including contract fabrication and foundry pathways; however, these options require further strengthening to ensure seamless commercial scaling.

This transition is underpinned by an **enabling layer** of specialised suppliers in photonics and single-photon detection, allowing system builders to qualify critical components locally and bypass fragile global supply chains.

The technical output is then hardened for the real world through **Packaging, Assembly, Integration, and Test (PAIT)**, providing the reliability evidence necessary to satisfy industrial procurement teams.
Finally, Scotland's **proving grounds (testbeds)** convert these technical specifications into credible operating narratives, utilising field-like testbeds to provide the adoption evidence required to shorten sales cycles and secure long-term economic capture.

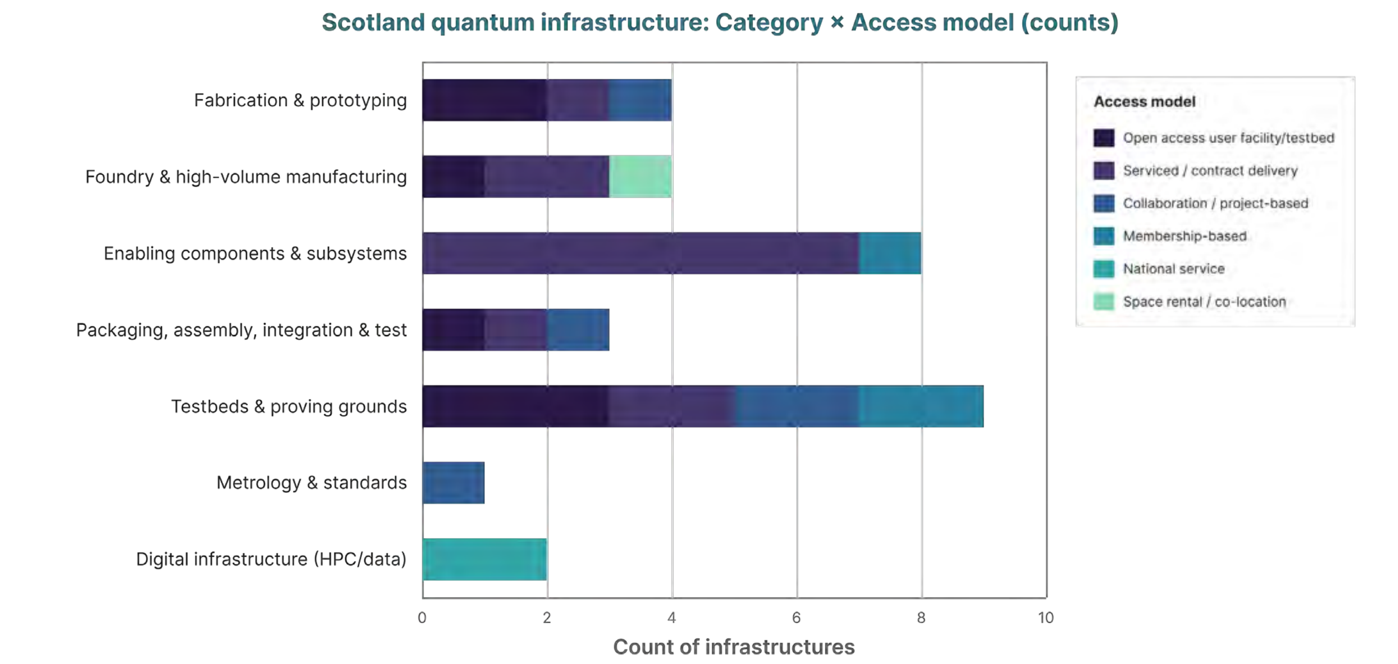


Fig. 3.2: Scotland's quantum infrastructure already forms a coherent, accessible foundation from build through integration to validation, enabling faster conversion of research into deployable capability and stronger local value capture.

3.2
The fabrication core

The foundation of any hardware-led technology ecosystem lies in its ability to design, fabricate, and test core physical devices. Scotland possesses a formidable and layered set of fabrication facilities that support the entire development lifecycle of quantum components, from initial university-based prototyping to industrial-scale foundry production. This infrastructure provides the essential capability to create the fundamental building blocks of quantum systems, including quantum processors, sensors, and photonic circuits.

Scotland's fabrication stack works because it offers a practical pathway: university cleanrooms for fast iteration, commercial translational capacity that can carry processes into paid work, then local foundry routes for scale and qualification. The strategic value is speed and de-risking; founders and industrial teams can iterate locally, harden a process, then move into higher-TRL[46] production without rebuilding the world from scratch.

3.2.1
University-led nanofabrication and prototyping

The initial stages of quantum device development, moving from theoretical concept to a physical prototype, are supported by a trio of world-class, university-hosted cleanroom facilities. These centres provide the advanced tooling and deep process expertise necessary for early-stage R&D and pilot-scale fabrication.

[46] Purohit, A., Kaur, M. and Seskir, Z.C. et al. (2023) 'Building a quantum-ready ecosystem', *IET Quantum Communication*. https://doi.org/10.1049/qtc2.12072

The **James Watt Nanofabrication Centre (JWNC)** at the University of Glasgow is a cornerstone of the UK's quantum research landscape (Fig. 3.3). As a 1600 m^2 cleanroom with a comprehensive suite of micro- and nanofabrication tools, it provides the fundamental capability for creating novel quantum devices from scratch. Its expertise spans electron-beam lithography for defining nanoscale features, plasma etching for shaping materials with atomic-level precision, and advanced deposition and metrology tools[47].

For the UK National Quantum Technologies Programme,

[47] University of Glasgow (n.d.) *About JWNC*. https://www.gla.ac.uk/research/az/jwnc/aboutjwnc/

James Watt Nanofabrication Centre

University of Glasgow

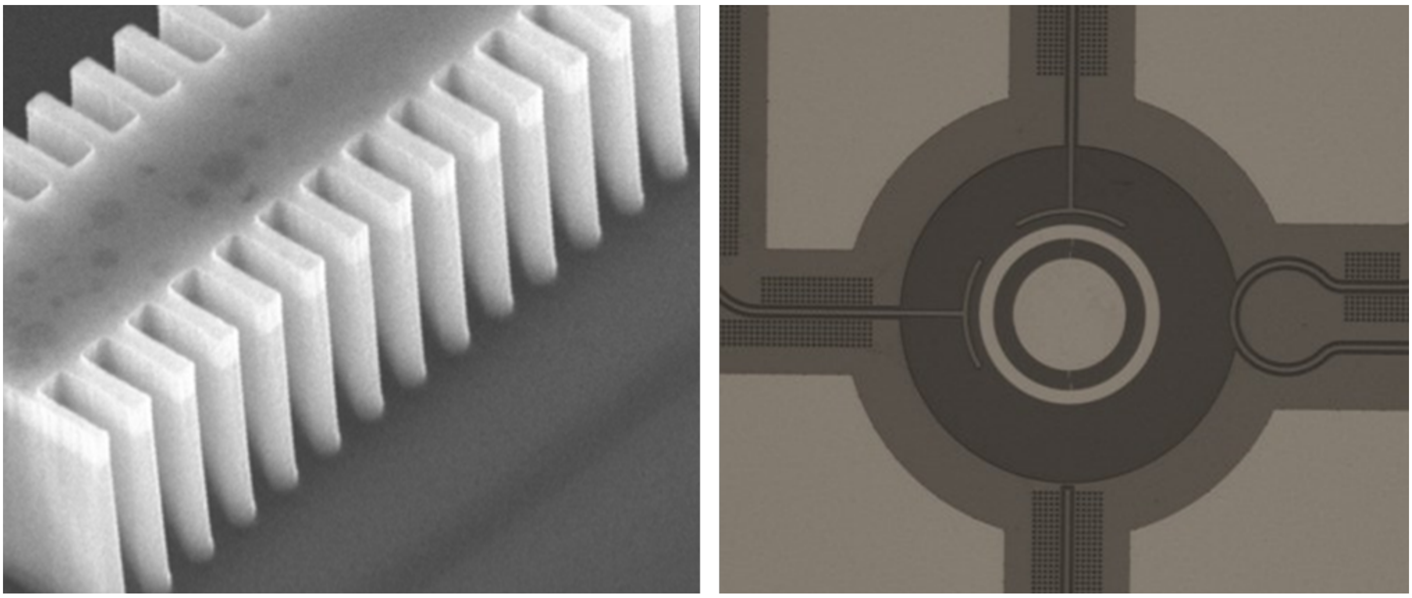


Fig. 3.3: Cutting-edge quantum components fabricated at the JWNC: (Left) A 780 nm DFB laser for Rubidium cold atom traps and (Right) a superconducting quantum circuit for next-generation computing (Image: JWNC).

JWNC states that it is delivering devices and circuits to all four Quantum Technology Hubs spanning quantum communications, sensing, imaging, and computing, including short-wave infrared single-photon detectors and imaging arrays, DFB lasers for cold-atom systems, photonic integrated circuits, MEMS vapour cells, grating magneto-optical traps, microfabricated ion traps, and superconducting qubit circuits[48].

Bridging the gap between academic research and industrial supply is **Kelvin Nanotechnology (KNT)**, the commercial arm of the JWNC. KNT operates a fab-lite model, leveraging the state-of-the-art toolset of the JWNC to provide contract R&D, prototyping, and manufacturing services to a global client base (Fig. 3.4). This unique arrangement provides a direct and streamlined commercialisation pathway for processes developed within the university. KNT has established itself as a leading supplier of miniaturised quantum components[49].

The **Scottish Microelectronics Centre (SMC)** at the University of Edinburgh provides complementary capabilities focused on silicon-based technologies[50]. As a 200 mm wafer-capable facility, the SMC offers a full suite of semiconductor and MEMS fabrication processes (Fig. 3.5). While not exclusively a quantum facility, its capabilities are critically enabling. SMC's core strength is a comprehensive process and metrology toolset for up to 200 mm silicon wafers (with tools configurable down to 75–150 mm), supporting post-processing of sub-micron CMOS alongside fabrication of a wide range of silicon and non-silicon microsystems. It also delivers serviced fabrication and processing for academia and industry and supports collaborative projects and spin-out activity.

Rounding out Scotland's university-led fabrication core is the **Institute of Photonics semiconductor microfabrication cleanroom** at the University of Strathclyde, based in the Technology and Innovation Centre (TIC) on George Street. It is an industry-standard cleanroom suite built for fabrication, test, and assembly of micro-scale optoelectronic and photonic devices, and it is explicitly set up for external engagement via hands-on access or serviced work[51].

[48] University of Glasgow (n.d.) *JWNC Research:* Quantum Technology. https://www.gla.ac.uk/research/az/jwnc/research/

[49] Kelvin Nanotechnology (n.d.) *Quantum*. https://kntnano.com/quantum/

[50] University of Edinburgh, School of Engineering (n.d.) *Scottish Microelectronics Centre (SMC)*. https://eng.ed.ac.uk/about/facilities/scottish-microelectronics-centre-smc

[51] University of Strathclyde, Institute of Photonics (n.d.) *Semiconductor Microfabrication Facilities*. https://www.strath.ac.uk/science/physics/instituteofphotonics/ourresearch/ourfacilities/semiconductormicrofabrication/

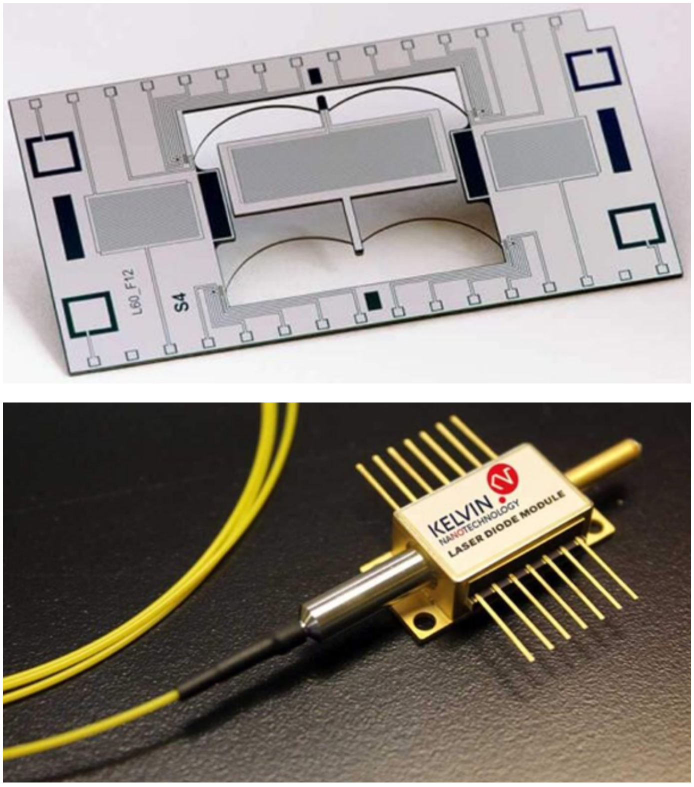


Fig. 3.4: High-precision quantum hardware from KNT featuring the Wee-g portable gravimeter (top) and an atomic-transition-tuned 780 nm laser module (bottom), both designed for next-generation navigation and sensing (Image: KNT).

Fig. 3.5: Pioneering microelectronics from the SMC: featuring a 96-element heater/sensor array for micro-cooling systems (top) and the world-class SMC fabrication (bottom) (Image: SMC).

This facility is specialised in the fabrication, testing, and assembly of optoelectronic and photonic devices, with particular expertise in III–V compound semiconductors like Gallium Nitride (GaN) and materials such as diamond and sapphire. These materials are crucial for creating high-performance components for quantum photonics, including custom laser sources, micro-LED arrays for atom addressing, and components for hybrid integrated photonics. The cleanroom provides both hands-on and serviced access, enabling the rapid prototyping of novel photonic components essential for quantum sensing and communication systems.

3.2.2

Commercial and open-access foundries

Once a quantum device clears prototype validation, the real bottleneck shifts from physics to manufacturability: repeatability, yield, test coverage, and a credible quality trail. Scotland's advantage is that this handover can be done locally through a small number of industrial fabrication routes that cover silicon and MEMS, III–V photonics, and SiC power devices. That reduces the "process translation penalty" that usually appears when teams are forced to move early hardware to unfamiliar, overseas lines.

Semefab in Glenrothes provides Scotland's most direct scale route for silicon and MEMS[52]. It operates two autonomous 6-inch wafer fabs, one for MEMS and one for CMOS/Bipolar processes, with in-house probe and test, plus device qualification and reliability assessment capability. In practice, this means teams can move from pilot MEMS structures into a foundry environment that already produces a broad range of MEMS sensors for OEMs, which is the kind of operational maturity required for sensor markets that demand repeatable performance and cost discipline.

[52] Semefab (n.d.) *Wafer Foundry Capabilities*. https://semefab.co.uk/wafer-foundry

Fig. 3.6: Clas-SiC Wafer Fab is the world's first dedicated open 150mm pure-play foundry to manufacture silicon carbide power semiconductors (Image: Clas-SiC Wafer Fab).

For III–V photonics, **Sivers Photonics** (Glasgow) provides an industrial route that is unusually complete for an ecosystem of Scotland's size[53]. Sivers states it can take customers from initial concept through custom design, prototyping, qualification, and into high-volume manufacturing, supported by its InP100 4-inch indium phosphide processing platform and 24/7 fab operation. This matters strategically because quantum communications and sensing programmes tend to bottleneck on dependable laser sources and photonic device repeatability more than on "one-off performance". Having a local III–V fabrication route reduces integration risk and shortens supplier qualification cycles.

Clas-SiC Wafer Fab[54] in Lochgelly is a distinct asset because it is explicitly positioned as an open foundry for 150 mm silicon carbide power semiconductors (Fig. 3.6). While this is not a quantum device line, it is directly relevant to the classical infrastructure that sets uptime and operating cost for quantum systems, especially where power conversion, thermal performance, optical properties, and robustness drive system reliability. The presence of an open-access SiC foundry in Scotland provides local quantum hardware companies with a significant advantage in developing robust and efficient control infrastructure.

Finally, **Diodes' Greenock wafer fab** adds depth in high-volume analogue and power semiconductor manufacturing. Diodes confirms the acquisition and ongoing operation of the Greenock facility, including continued manufacture of analogue products and the scale of the site's wafer capacity[55]. Even where the site is not an open foundry, its presence strengthens Scotland's supply chain density in the components that sit around every quantum platform: power management, signal conditioning, and mixed-signal support electronics.

Taken together, these foundry routes make Scotland's fabrication stack commercially legible. A team can prototype in university cleanrooms, then transition into

[53] Sivers Semiconductors (2022) *Corporate Overview Leaflet: InP100 Product Platform*. https://www.sivers-semiconductors.com/wp-content/uploads/2022/08/Corporate-Overview-Leaflet_220619.pdf

[54] Clas-SiC Wafer Fab (n.d.) About: Open Foundry, ISO Class 5 Equipment. https://clas-sic.com/about/

[55] Diodes Incorporated (n.d.) *Completes Acquisition of Greenock, Scotland Wafer Fabrication Facility and Operations*. https://www.diodes.com/about/news/press-releases/diodes-incorporated-completes-acquisition-of-texas-instruments-greenock-scotland-wafer-fabrication-facility-and-operations

local industrial lines that can carry process control, test discipline, and quality evidence forward. That is what de-risks the move from "working device" to "buyable product" without forcing companies to build dedicated production infrastructure too early.

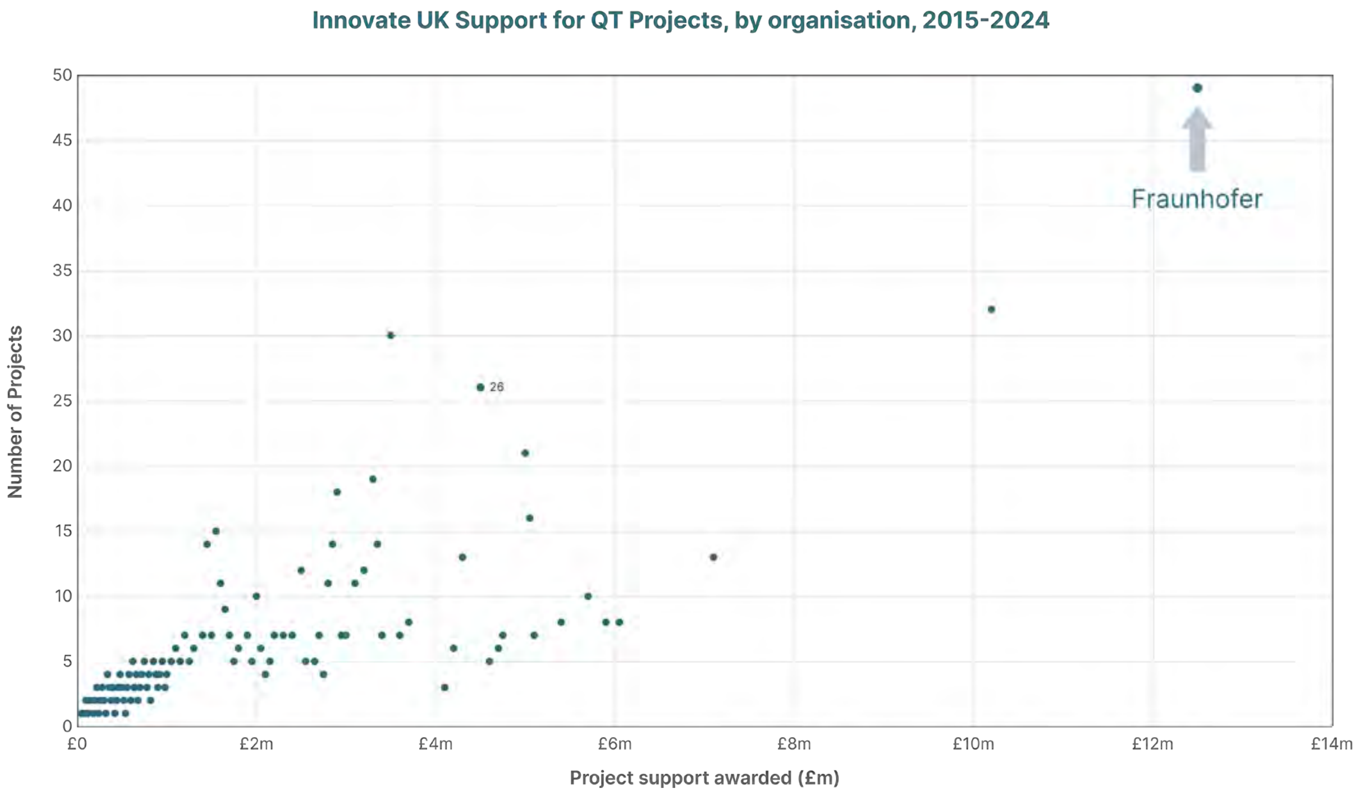
3.2.3
The enabling layer

This layer is where quantum moves from controlled experiments to deployable systems. For example, optical stability sets performance and reliability. If sources drift, beams cannot be shaped repeatably, coupling losses rise, coatings fail under power, or detectors cannot time-tag at throughput, system performance collapses before the physics does.
Scotland's advantage is that these enabling functions are held as local infrastructure that teams can access and procure, not as a fragmented set of distant suppliers.

Coherent Glasgow anchors industrial laser build and test capability at scale. By co-locating picosecond and femtosecond manufacturing in a volume production facility, Scotland gains repeatable production discipline in ultrafast sources that are widely used across quantum optics workflows and quantum materials characterisation.

Fraunhofer CAP plays a central translational role in Scotland's quantum industry by converting Scotland's strong photonics base into deployable quantum products, processes and demonstrators. Its contribution sits between university research and industrial adoption, supporting business-led R&D across sensing, imaging, quantum communications and quantum computing, while providing applied photonics expertise from sources to full systems (Fig. 3.7). Through Innovate UK and wider QT programmes, Fraunhofer CAP has supported real-world demonstrators including cold-atom PNT systems, satellite-to-ground quantum communications, hydrogen sensing, underwater communications, SPAD-based imaging and miniaturised optical assemblies. This makes it a key commercialisation bridge for Scotland's quantum ecosystem: de-risking prototypes, packaging complex optical systems, helping companies move from breadboards to robust products and strengthening the industrial pull-through of Scotland's quantum and photonics capabilities.

QT Assemble is explicitly designed to shrink optical benches into integrated subsystems by tackling size, weight, power and reliability through assembly processes such as waveguide writing, nanoscale



alignment and monolithic integration (Fig. 3.7). This is infrastructure that turns “works on a table” into “can be qualified”.

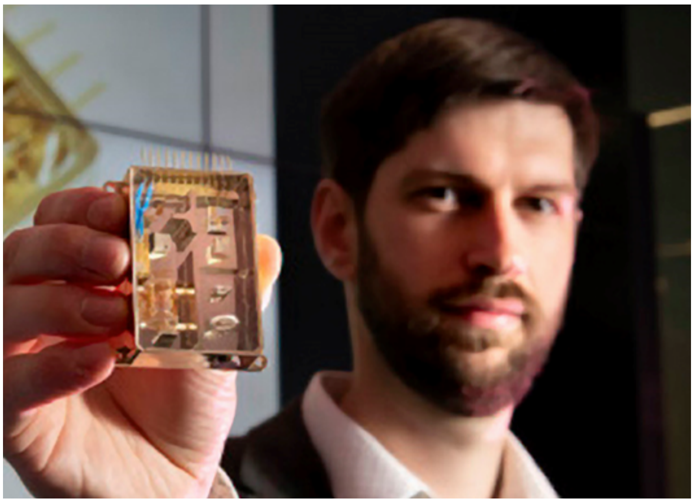


Fig. 3.7: Dr. Loyd McKnight, Head of Centre at Fraunhofer CAP, with a high-performance compact tapered amplifier (MOPA) system. This miniaturised laser engine combines a low-noise distributed feedback (DFB) diode laser with a tapered amplifier chip from Coherent to provide the stable, high-power light required for portable atom interferometers. The technology is designed as an economic tool to measure local gravity gradients for finding sinkholes, locating pipelines, and mapping oil field depletion (Images: Fraunhofer CAP).

Scotland then covers the practical bottlenecks that decide whether photonics scales:

PowerPhotonic (Dalgety Bay) provides wafer-scale freeform micro-optics and beam-shaping capability. This is the infrastructure that converts raw laser output into controlled field profiles, which directly affects trap quality, stability and system repeatability.

Optoscribe (Livingston) targets the fibre-to-PIC interface with laser direct-write glass interconnect components designed for high-volume automated assembly. That shifts coupling from a fragile craft step into an engineered packaging step.

Helia Photonics (Livingston) underpins loss and lifetime through optical coatings and photonics backend processing. Its coating stack capability extends to ultra-high reflectivity mirrors for low-loss systems and active work on high-reflectance mirrors for high-finesse microcavities. It also provides photolithography and extensive metrological and tribological characterisation testing services.

Photon Force (Edinburgh) supplies time-tagging SPAD cameras with published performance figures and an OEM route aimed at embedding single-photon timing in volume products. This is critical infrastructure for quantum imaging, time-resolved photon counting and deployable sensing payloads.

3.2.4
Packaging, Assembly, Integration, and Test (PAIT)

Packaging is where quantum hardware earns the right to ship. It is the step that locks in **electrical performance** (RF integrity, grounding, cross-talk control), **optical performance** (alignment and coupling stability), and **thermal performance** (heat extraction, drift control) while creating a reliability and qualification trail that procurement can trust.

Scotland’s strength is that this capability exists as infrastructure that teams can access locally, rather than being a late-stage dependency that forces an offshore handover.

ALTER Technology UK is the clearest “design-to-qualification” back-end route in the Scottish stack because it explicitly covers **microelectronic packaging, assembly, testing, and qualification** for ICs, ASICs, MEMS and sensors as well as optoelectronic devices. That matters for quantum because it supports the full module boundary, not just a package. Packaging choices decide whether control electronics remain stable, whether sensor readout stays low-noise, and whether the device can be integrated into a larger system without re-engineering.

At the system and scale-up layer, National Manufacturing Institute Scotland (**NMIS**) is no longer only “advanced manufacturing support”, it is building

NMIS
National Manufacturing Institute Scotland

Fig. 3.8: National Manufacturing Institute of Scotland supports advanced semiconductor packaging and integration (Image: NMIS).

dedicated semiconductor PAIT capacity through National Advanced Semiconductor Packaging and Integration Centre **(NASPIC)**, positioned as the UK's only open-access semiconductor packaging and integration facility (Fig. 3.8). This is directly relevant to quantum because the integration bottleneck is often electronics-led: packaging, interconnect, and integration of control and readout stacks into compact, serviceable assemblies.

NMIS has also publicly reported major funding to expand semiconductor manufacturing capabilities and advanced packaging, signalling that Scotland is actively deepening this infrastructure rather than just mapping what already exists. A concrete quantum-facing signal inside NMIS is the industry doctorate project with **SeeQC UK** on assembling control architecture for integrated quantum circuits, which is precisely the kind of integration challenge that sets the pace for scalable quantum computing.

3.2.5

Testbeds and field environments

Quantum hardware only becomes bankable once it has survived the real world. The decisive question is no longer "can it work" but "can it be qualified, integrated and repeated under operational constraints". Scotland's proving-ground infrastructure compresses that transition by giving developers places to validate space readiness, network integration and system-level deployment without exporting risk to another geography.

Space and communications: Scotland's space-facing test infrastructure is valuable because it removes two failure points that routinely kill programmes: qualification bottlenecks and integration friction.

At the national-instrumentation end, **UK ATC and the Higgs Centre for Innovation** (Royal Observatory of Edinburgh)[56] provide space-grade build environments and test capability that can be used to harden quantum payloads and their classical support electronics. The Higgs Centre explicitly positions itself around end-to-end "build and test" support including environmental and functional test infrastructure, giving teams a route to evidence that a payload is flight-ready rather than merely lab-ready.

The Quantum Communications Hub **Optical Ground Station (HOGS)**, within the grounds of Heriot-Watt University's Edinburgh campus represents a

[56] UK Space Facilities (n.d.) *Higgs Centre for Innovation.* https://www.higgscentre.org/

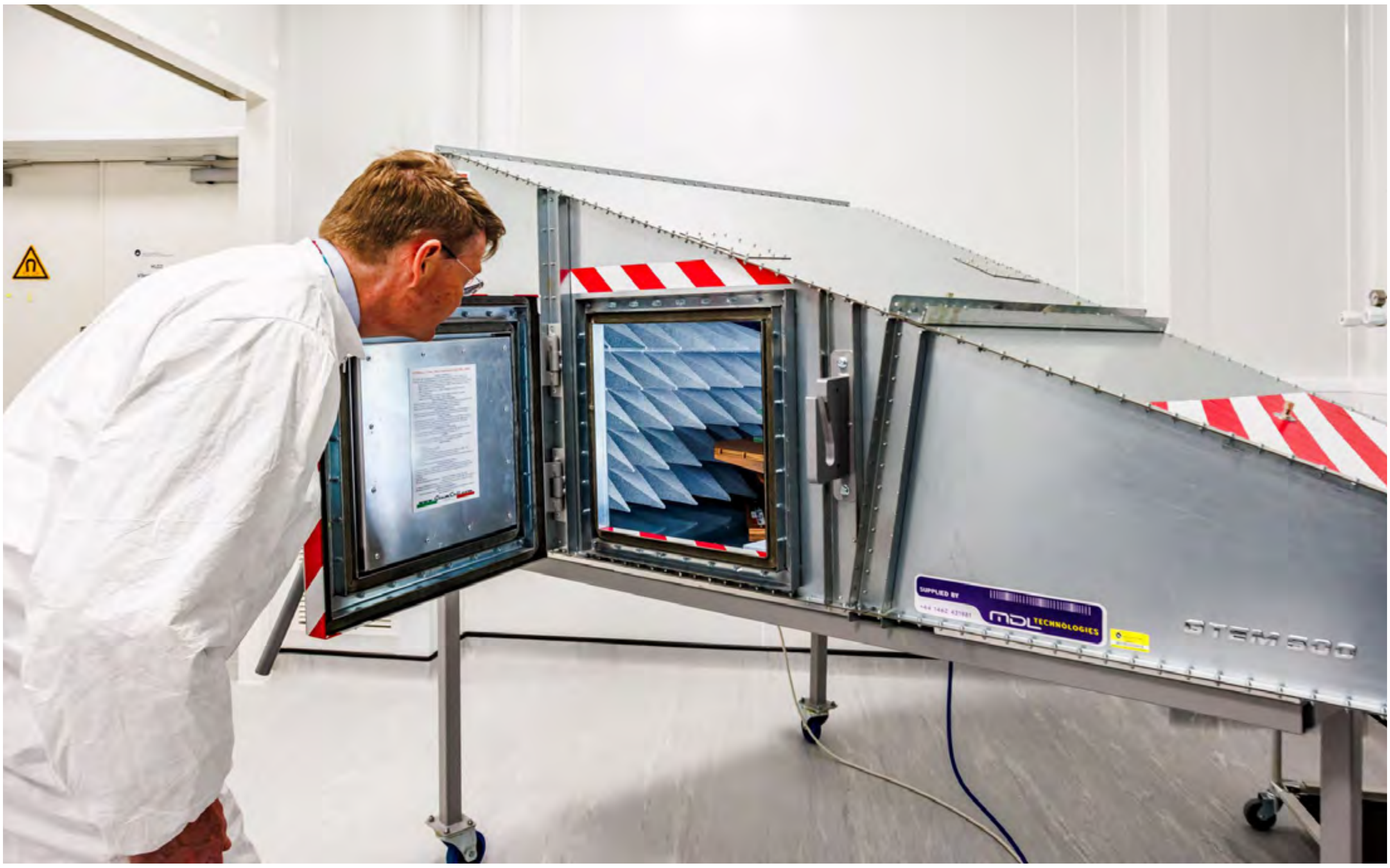


Fig 3.9: The Higgs Centre for Innovation offers state-of-the art clean rooms and advanced testing equipment (Image: STFC).

Fig. 3.10: Dr Ross Donaldson, project lead from Heriot-Watt University's Institute of Photonics and Quantum Sciences, at the HOGS facility in the Heriot-Watt University's Edinburgh campus (Image: Heriot-Watt University).

significant leap forward in the UK's space and quantum capabilities[57]. Using advanced laser technology to communicate with satellites in ways that could make data breaches a thing of the past, HOGS marks a transition from traditional radio frequency communications to optical links that offer significantly higher data rates and improved security. The facility will shortly add state-of-the-art single-photon detectors and adaptive optics systems capable of exchanging quantum-encrypted information with orbiting satellites. This technology could eventually form the backbone of an ultra-secure quantum internet within the UK. Beyond its cybersecurity focus, the facility will monitor and track space debris which is a growing concern as Earth's orbit becomes increasingly congested. The facility will also pioneer new techniques in high-speed optical communications that could power future 6G networks and beyond.

On the "get it into orbit" side, Glasgow-based satellite manufacturers create a practical route from lab payload to integrated mission. **AAC Clyde Space** positions itself around end-to-end mission services (concept to orbit) which matters because quantum payload teams can focus on the optical or timing core while relying on an established mission pipeline for platform, integration and operations[58]. **Spire Global** anchors a high-throughput build-and-test capability in Glasgow and expanded its manufacturing and test footprint at Skypark in 2025, explicitly framing the site as a single-building design–build–test–integrate facility. For quantum, the strategic value is optionality: payload teams gain local access to satellite integration culture and test discipline without having to create it from scratch. For terrestrial comms and networked deployment, Scotland's private 5G testbeds matter less for "connectivity" and more for controlled pilots where security, latency and edge integration can be evaluated with real operational stakeholders. **The S5GConnect testbeds** are presented as live and open-to-market, enabling trials in sectors such as manufacturing and environmental monitoring. At the same time, the Scotland 5G Centre has also publicly

[57] Heriot-Watt *University (2025) University Unveils New £2.5M Quantum-Enabled Optical Ground Station.* https://www.hw.ac.uk/news/2025/university-unveils-new-2.5m-quantum-enabled-optical-ground-station

[58] Science and Technology Facilities Council (n.d.) *AAC Clyde Space*. UK Space Facilities. https://www.ukspacefacilities.stfc.ac.uk/Pages/AAC-Clyde-Space.aspx

Fig 3.11: Spire Global anchors a high-throughput build-and-test capability in Glasgow (Image: Spire Global).

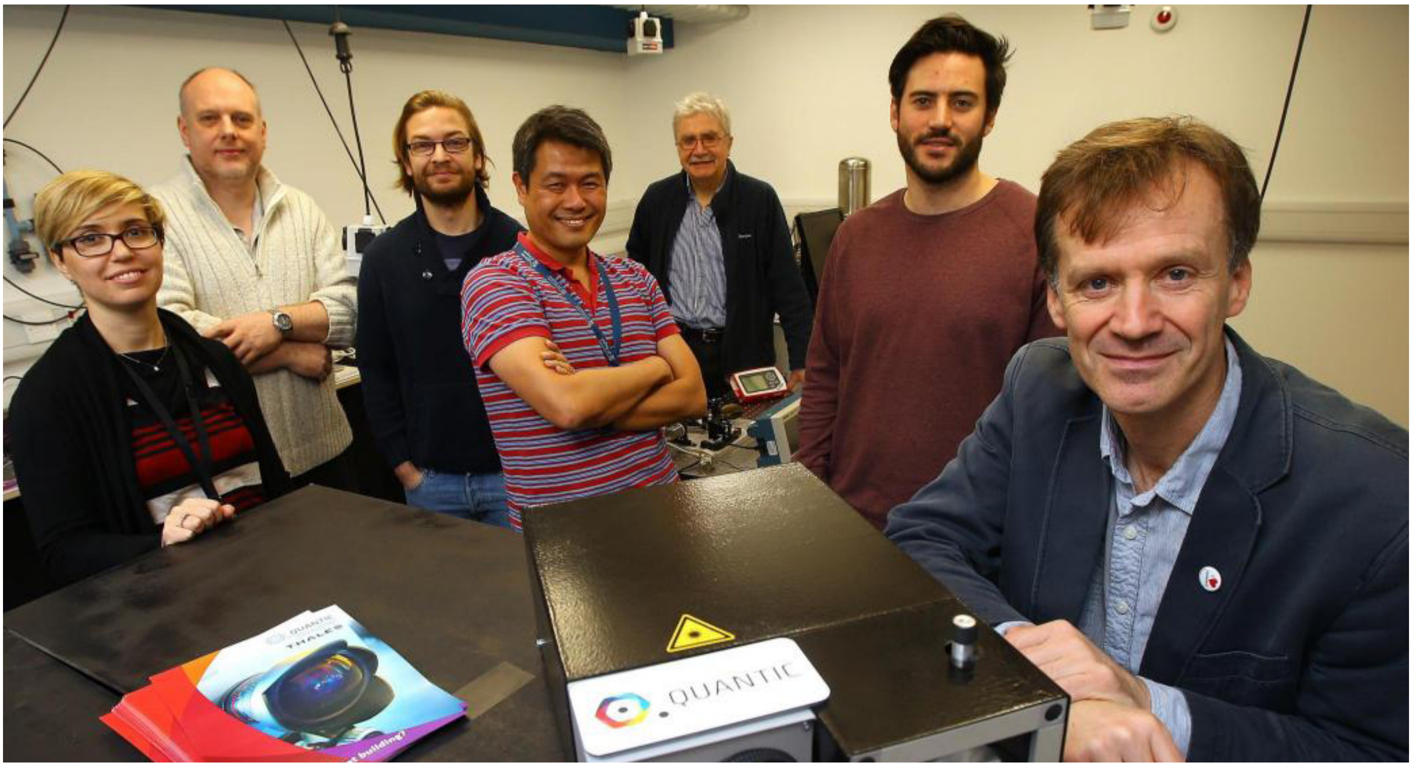


Fig. 3.12: Professor Miles Padgett (right), principal investigator at QuantIC at the University of Glasgow. Prof Padgett is pictured with a low-cost 3D single pixel camera in one of the labs at the UK Quantum Phase-1 hub (Image: University of Glasgow).

stated that it concluded it was no longer feasible to keep the centre and hubs operational, which makes the existence of the testbed footprint and partner-led access routes even more relevant as the durable infrastructure outcome.

Sensing and system integration: Scotland's space-facing test infrastructure is valuable because it removes two failure points that routinely kill programmes: qualification bottlenecks and integration friction.

QuantIC, led by the University of Glasgow as the UK Quantum Technology Phase 1 Hub in Quantum Imaging, previously operated dedicated labs and a purpose-built co-innovation space that enabled industry-facing prototyping and demonstrator development (the EPSRC hub award ran Dec 2019 to Nov 2024). Its outputs and facilities supported application-led quantum imaging demonstrators, including methane gas-imaging via single-pixel imaging approaches and broader quantum-enhanced imaging capabilities targeted at seeing through obscurants (fog and smoke) and biomedical/inside-body imaging contexts.

The **National Robotarium**, a joint venture between Heriot-Watt University and the University of Edinburgh, is a world-leading centre for robotics and AI. Its advanced laboratories provide a unique proving ground for integrating quantum sensors onto mobile and autonomous platforms. This allows for the demonstration of powerful new capabilities, such as a robot equipped with a quantum gravimeter mapping underground voids for civil engineering, or an autonomous vehicle navigating without GPS using a quantum inertial sensor.

CENSIS, Scotland's innovation centre for sensing, imaging and IoT, is an important regional enabler of innovation. Through its work with companies and public-sector partners to de-risk projects and accelerate technology adoption, it strengthens the broader sensing and imaging environment in which emerging technologies, including quantum-enabled approaches, can find application.

Fig. 3.13: A 150 mm silicon wafer made at the University of Glasgow's James Watt Nanofabrication Centre (JWNC), etched by electron-beam lithography and plasma processing to depict Scotland, including a ~50 µm-wide River Clyde and a Glasgow 850 logo built from thousands of tiny repeats, using black silicon plus sub-wavelength holographic gratings to give iridescent highlights (also seen in the cover for this chapter). Image: University of Glasgow).

The Power Networks Demonstration Centre **(PNDC)** is a particularly strategic proving ground because it is a real grid environment, not a synthetic lab setup. That matters for quantum timing and synchronisation use-cases as well as magnetic and field-sensing concepts, because grid adoption is won through deployment and assurance[59]. Underpinning credibility across these deployments is **NPL Scotland**, hosted at Strathclyde's Technology and Innovation Centre, which anchors measurement assurance and time and frequency capability. NPL's role is the trust layer: it makes device outputs traceable, comparable and defensible to industrial buyers and regulators.

Scotland's proving grounds reduce the "adoption gap" by making operational evidence cheap to generate and hard to dispute. Instead of relying on claims of theoretical advantage, the ecosystem can demonstrate space readiness, network integration and measurement credibility inside local infrastructure, which is exactly what buyers need before they commit to first deployments.

[59] Liu, Y., Sun, B. and Wu, Y. et al. (2025) 'Time Synchronisation Techniques in the Modern Smart Grid: A Comprehensive Survey', *Energies*, 18(5), 1163. https://doi.org/10.3390/en18051163

3.2.6

The digital backbone

The development of complex quantum hardware is inextricably linked to the availability of powerful classical computing resources. High-performance computing (HPC) is an essential tool across the entire quantum R&D lifecycle, from the ab initio simulation of new quantum materials and the design of quantum circuits to the optimisation of experimental control parameters and the analysis of the vast datasets that quantum systems produce.

Scotland is in the strategically advantageous position of hosting the UK's national supercomputing centre, providing its quantum ecosystem with unparalleled access to world-class digital infrastructure.
Edinburgh Parallel Computing Centre (EPCC) at the University of Edinburgh provides Scotland's core "classical computing backbone" for quantum R&D, spanning verification, co-design and hybrid workflow development[60,61].
The flagship system is ARCHER2, the UK National High Performance Computing (HPC) Service, an HPE Cray EX with 748,544 CPU cores that enables large exact state-vector simulations where cost scales exponentially with qubit count. EPCC's Quantum Applications Group has demonstrated 44-qubit circuit simulation on ARCHER2 using the QuEST library, strengthening classical verification for near-term hardware and informing error-correction work.

Alongside ARCHER2, Cirrus (a heterogeneous CPU and GPU UK National Tier-2 HPC service) supports hybrid quantum–classical loops, while the Edinburgh International Data Facility (EIDF) provides secure scalable compute and data services for experiment and simulation pipelines.

Looking ahead, the UK Compute Roadmap commits up to £750m for a new national supercomputer service at EPCC to replace ARCHER2, positioning the ecosystem for materially larger and higher-fidelity simulation and co-design as systems scale.

Alongside compute, the Quantum Software Lab in Edinburgh strengthens the translation layer, focusing on use-case identification, algorithm and software development, and validation with end-users to turn infrastructure into deployable capability.

[60] EPCC (n.d.) ARCHER2: *UK National High Performance Computing Service*. https://www.epcc.ed.ac.uk/hpc-services/archer2

[61] EPCC (2023) *Simulating quantum circuits on GPUs*. https://www.epcc.ed.ac.uk/whats-happening/articles/simulating-quantum-circuits-gpus

3.2.7

Scotland's quantum story

Glasgow Science Centre is emerging as one of Scotland's main public-facing channels for quantum engagement, turning research into hands-on experiences through its dedicated interactive gallery "Quantum Technologies: Making the Invisible Visible" (Fig. 3.14) and associated live explainers and Q&A activity with the QuantIC community.

Alongside the exhibit, its public engagement programme supports workshops, talks and other events that help non-specialists understand how quantum sensing, imaging and related technologies translate into real-world applications.

The co-location of the UK's premier digital infrastructure at EPCC with the dense cluster of physical quantum fabrication and testing facilities in Glasgow and the Central Belt creates a uniquely powerful innovation environment. This proximity enables a rapid and efficient feedback loop that accelerates the entire design–build–test cycle.

This tight integration of world-class digital and physical infrastructure, contained entirely within the Scottish ecosystem, shortens development timelines, improves R&D efficiency, and constitutes a formidable competitive advantage.

The strategic gap is at productisation (transforming customised, one-off services into standardised, packaged offerings with a fixed scope), not discovery: packaging, assembly, integration and test capacity is still uneven across modalities and access routes are fragmented, which slows SMEs and pushes mid-TRL work to easier pathways outside Scotland. A second friction is basic but material, there is no single, trusted live database that shows what infrastructure exists, who can access it and under what terms, which limits resource-sharing and collaboration. The mitigation is to treat shared PAIT as national infrastructure with a simple front door (database plus standardised access) and fast, subsidised routes for SMEs, then use mission-led, end-user anchored demonstrators to lock in recurring demand for Scottish-made photonics,

Fig 3.14: Glasgow Science Centre houses an interactive gallery dedicated to quantum technologies (Image: Glasgow Science Centre).

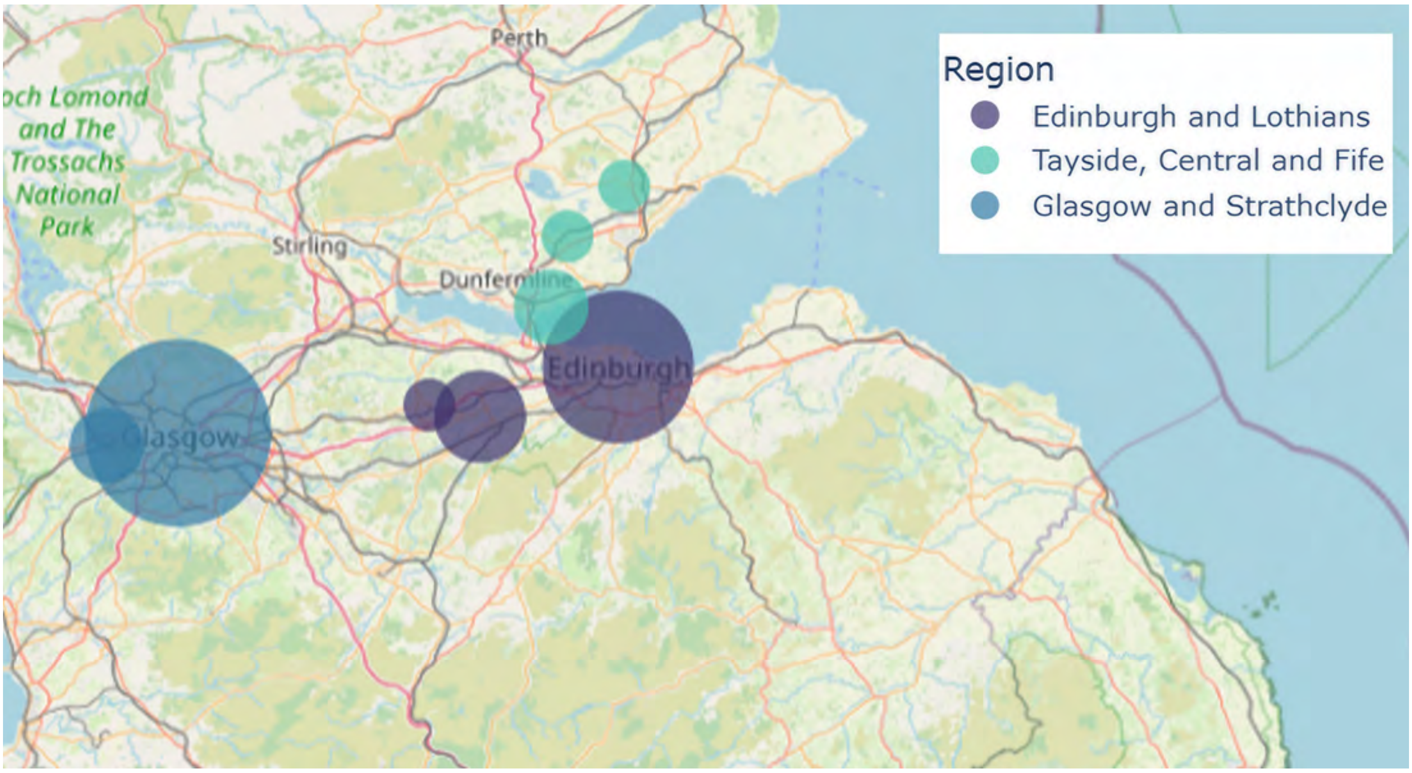


Fig.3.15: Scotland quantum infrastructure cluster map, with bubble area proportional to the number of mapped assets for the given region

cryogenics and room-temperature electronics. Protect this advantage by building a technician and engineer pipeline aligned to the infrastructure itself so scaling is limited by throughput, not people.

The following table shows a non-exhaustive list of Scotland's quantum-enabling infrastructures, grouped by capability (micro/nanofabrication, commercial fabs, enabling components and subsystems, packaging and integration, application testbeds, metrology and standards, digital infrastructure, and public engagement), with operator, region, and access model indicated for each asset.

Followed by the Access Model definitions:

- **OA** = Open access (available beyond the host organisation, typically via published process and fees or standard facility access routes)
- **SV** = Service access (delivered as a staff-run service or contract manufacturing rather than open tool access)
- **RN** = Restricted network (access limited to a defined institutional user base or partner network, not generally open)
- **CO** = Collaboration only (access primarily through a funded collaboration or joint project with the host)
- **OA/MB** = Open access, membership-based (open route exists but prioritised or structured via membership/subscription)
- **NS** = National service (access via national allocation or peer-reviewed calls, e.g. UK national HPC services)
- **PL** = Planned (committed or announced capability not yet operational)

Category	Infrastructure	Operator	Region	Access model
Micro/nanofabri-cation & prototyping	James Watt Nanofabrication Centre (JWNC)	University of Glasgow	Glasgow and Strathclyde	OA + SV
	Scottish Microelectronics Centre (SMC)	University of Edinburgh	Edinburgh and Lothians	RN
	Strathclyde semiconductor microfabrication facilities	University of Strathclyde	Glasgow and Strathclyde	OA
Commercial fabs and foundries	Kelvin Nanotechnology (KNT)	University of Glasgow	Venture Capital & Software	SV
	Semefab silicon/MEMS foundry	Semefab	Tayside, Central and Fife	SV
	Scotland III–V photonics manufacturing base	Sivers Photonics (Sivers Semiconductors)	Glasgow and Strathclyde	SV
	Clas-SiC open foundry + ISO Class 5 cleanroom facility	Clas-SiC Wafer Fab	Tayside, Central and Fife	SV
	High-volume analogue/ power fab	Diodes Incorporated	Glasgow and Strathclyde	SV
	Ion implantation	Ion Beam Services (IBS)	Edinburgh and Lothians	SV
Enabling components and subsystems	Fraunhofer Centre for Applied Photonics (Fraunhofer CAP)	Fraunhofer UK	Glasgow and Strathclyde	SV
	Laser material processing/ freeform micro-optics	PowerPhotonic	Tayside, Central and Fife	SV
	Coherent Glasgow ultrafast laser manufacturing centre	Coherent	Glasgow and Strathclyde	SV
	Photonic interconnect components (glass-based integrated photonics)	Optoscribe (Intel post-acquisition)	Edinburgh and Lothians	SV
	Wafer-scale freeform micro-optics	PowerPhotonic	Tayside, Central and Fife	SV
	Helia Photonics (optical coatings + back-end processing)	Helia Photonics	Edinburgh and Lothians	SV
	Photon Force (custom SPAD/TCSPC cameras & sensors)	Photon Force	Edinburgh and Lothians	SV

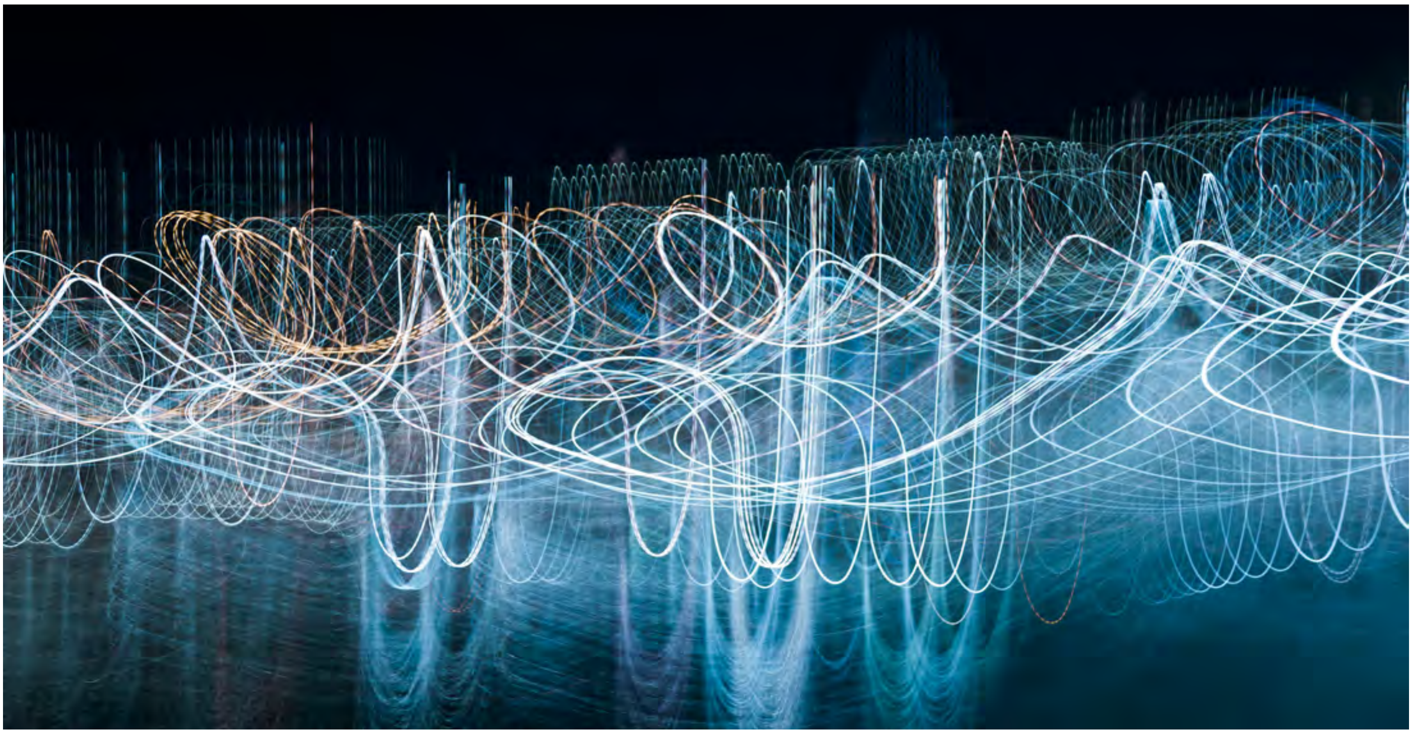
Category	Infrastructure	Operator	Region	Access model
Packaging, assembly, integration and test	Outsourced Semiconductor Assembly and Test (OSAT)	ALTER Technology UK (Optocap)	Edinburgh and Lothians	SV
	Advanced Semiconductor packaging and Integration	National Manufacturing Institute Scotland (NMIS)	Glasgow and Strathclyde	CO
Application testbeds and proving grounds	Qualification & test facilities for space payloads (incl. quantum payloads)	UK ATC & Higgs Centre for Innovation	Edinburgh and Lothians	SV
	Space payload integration (small satellites)	AAC Clyde Space	Glasgow and Strathclyde	SV
	Optical ground station/ free-space links	Heriot-Watt Optical Ground Station (HOGS)	Edinburgh and Lothians	CO
	Industry projects integrating sensors/ imaging into wider systems	CENSIS	Glasgow and Strathclyde	CO
	LV/MV network testbed for sensing and timing in power grids	Power Networks Demonstration Centre (PNDC)	Glasgow and Strathclyde	OA + MB
	Platform integration/trials for sensors (navigation, imaging, subsurface etc.)	National Robotarium	Edinburgh and Lothians	CO
	Satellite platform for hosting payloads	Spire Global	Glasgow and Strathclyde	SV
	Networks & edge testbeds for deploying secure comms and sensing pilots	Scotland 5G Centre	Glasgow and Strathclyde	OA
Metrology and standards	Time & frequency, quantum metrology	NPL Scotland	Glasgow and Strathclyde	CO
Digital infrastructure	Use-case identification, quantum algorithm/ software development, validation with end-users	Quantum Software Lab (QSL) (with NQCC)	Edinburgh and Lothians	CO
	HPC for simulation, algorithm development, hybrid workflows	EPCC (ARCHER2 / national HPC services)	Edinburgh and Lothians	NS
	UK Exascale HPC (planned)	EPCC / UKRI	Edinburgh and Lothians	PL
Public Infrastructure	Public awareness and education	Glasgow Science Center	Glasgow and Strathclyde	

CHAPTER

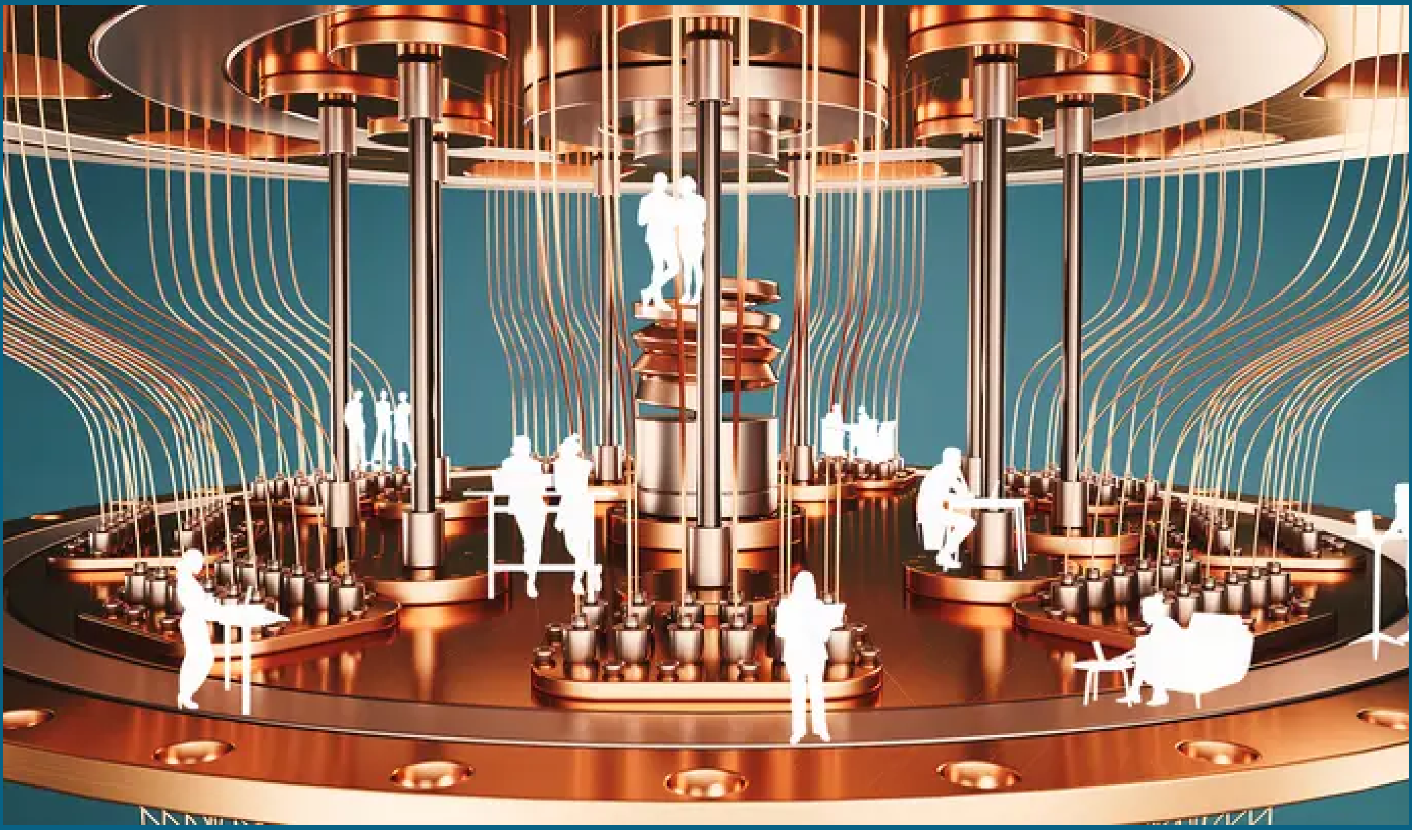
04

Skills and Talent

Building the quantum-ready workforce in Scotland



Executive Summary



Scotland's starting position is strong in quantum talent - what matters now is converting that strength into a broader delivery workforce. The ecosystem already sustains high-calibre talent creation through concentrated academic strength, established postgraduate training routes and a steady pipeline of early-career researchers (ECR) who gain direct exposure to advanced infrastructure. This gives Scotland a credible platform to build a quantum-ready workforce that supports both technology development and delivery, with particular advantage in hardware-adjacent domains that align naturally with Scotland's wider industrial base.

The evidence in this chapter suggests Scotland's current model is most visible and most mature at the specialist end, where research training and dedicated MSc and CDT pathways are performing well. In parallel, employers increasingly need quantum-literate engineers and technicians who can run facilities, support integration and verification and take systems into operational environments. These roles sit across the applied engineering layer: photonics integration, nanofabrication, packaging, control electronics, vacuum and cryogenics operations, calibration and field applications. Strengthening these pathways does not dilute Scotland's specialist pipeline. It complements it by increasing throughput, widening entry routes and making talent supply more scalable.

Taken together, Scotland's workforce agenda should be positioned as building depth and breadth at the same time. It strengthens the postgraduate and early-career research engine while systematically expanding the applied engineering and technician base through upskilling, modular training and new entry routes. In parallel, it grows local talent through industry placements and clear progression pathways, and it increases attraction of specialist expertise from elsewhere to accelerate capability build-out. The outcome is a workforce that is larger, more deployable and faster to become productive, with a tighter handover between research, engineering integration and real-world deployment across Scotland's quantum ecosystem.

Findings	Implication	Scotland-specific mitigation
A world-class academic pipeline Scotland has a strong specialist talent engine through its universities, MSc routes and doctoral cohort training, with a sizeable early-career research layer connected to advanced infrastructure.	This provides a stable foundation for frontier capability and technical leadership, and it creates a pipeline that can be converted into industry roles through structured transition mechanisms	Maintain and grow specialist routes while strengthening conversion mechanisms: industry rotations for ECRs, structured placements and clearer pathways into systems, test and product roles within Scottish firms.
The "missing middle" The education system heavily prioritises postgraduate quantum physics but ignores the vocational pathways required for hardware manufacturing.	SMEs cannot afford to spend 12 months training a new hire to be commercially productive. Without practical, hands-on exposure, the talent pipeline chokes SME agility.	Stop relying solely on universities. Partner with Further Education (FE) colleges to launch targeted apprenticeships for vacuum, cryogenics, and electronics technicians, embedding "quantum engineering" modules into standard HND/BEng qualifications. Make use of other private actors as well.
The ECR "flight risk" Talent attraction and retention should be prioritised for long-term win. Scotland's valorisation and programme ecosystem can shape the labour market through how placements, secondments, transition posts and upskilling are funded and coordinated.	Without a financial safety net or commercial infrastructure, researchers and potential founders choose stable academic posts abroad rather than building in Scotland.	1. Deep tech founder fellowships: launch a prestigious, salary-backed fellowship that pays researchers to leave academia and build a company, providing a 24-month financial runway + commercial mentorship to de-risk the startup leap. 2. Implement a support ecosystem—including relocation grants, "soft landing" services for families, and rapid visa processing—that makes Scotland the most personally and professionally supportive environment for quantum entrepreneurs to build their lives.

4.

Workforce strategy

Central to securing a competitive advantage in this emerging landscape is the cultivation of a highly skilled, multi-disciplinary workforce. The United Kingdom has recognised this imperative, placing skills and talent at the core of its £2.5 billion National Quantum Strategy, which aims to establish the UK as a world-leading, quantum-enabled economy.

Nationally, this demand has been recognised, and the direction of travel is clear[62]. The emerging design principles are practical: use apprenticeships and modular training as high-leverage routes by embedding quantum-relevant content into existing standards and engineering pathways, rather than treating quantum as a standalone track. There is also a consistent emphasis on clearer signposting of vocational routes, stronger coordination across the ecosystem and a more deliberate approach to attracting and retaining specialist talent. Scotland is well placed to implement these principles quickly because its facilities density and applied centres enable training to be anchored in real operating environments, not simulated contexts. Local feedback reinforces what makes workforce measures succeed in practice.

The enabling ecosystem is asking for hands-on skills exposure that is systematic rather than incidental, placements that are long enough to move learners from observation to contribution and commercial literacy that supports spinout formation and SME growth.

This points to a workforce strategy that is ambitious but grounded: build multiple entry routes, make practical training routine, reduce friction for SMEs to host and hire talent and use existing translation and funding actors as workforce shapers through placements, secondments and targeted upskilling.

4.1

Scotland's academic powerhouse

Scotland's capacity to compete globally in quantum technologies is founded upon a concentrated powerhouse of academic institutions that serve as the primary engine for talent generation and early-stage capability creation.

[62] Department for Science, Innovation and Technology (2025) *UK Quantum Skills Taskforce Report*. HM Government: London. https://www.gov.uk/government/publications/uk-quantum-skills-taskforce-report/uk-quantum-skills-taskforce-report

Fig. 4.1: The University of Glasgow.

4.1.1

University of Glasgow

Glasgow is one of Scotland's most important quantum anchors because it combines frontier science with the infrastructure and engineering capacity to build, test and supply real devices. That combination has allowed the University to move from early UK leadership in quantum imaging into the current mission cycle where resilience, deployability and sovereign capability are the organising principles.

Elements that make University of Glasgow especially important to Scotland's workforce and deployment strategy:

1. **Resilient Position, Navigation and Timing (PNT) as a national mission**

The University leads the UK Hub for Quantum Enabled Position, Navigation and Timing (QEPNT). The hub is framed explicitly around reducing reliance on satellite navigation and delivering systems that still work when GNSS is unavailable or unreliable, with relevance to critical national infrastructure and national security. The technology focus includes atomic clocks and quantum inertial sensing plus hybrid approaches that can be engineered into deployable platforms.

Fig. 4.2: UK Hub for Quantum Enabled Position, Navigation & Timing (QEPNT) representatives (image: QEPNT).

2. **Imaging and sensing leadership that has already translated into industry outcomes**

Glasgow led QuantIC, the UK quantum hub for quantum enhanced imaging in the first hub cycle, establishing deep capability in quantum imaging and sensing. UKRI reporting on QuantIC points to concrete translation outcomes including company formation, licensing and product prototypes, which is important for Scotland because it demonstrates a repeatable pathway from lab capability to commercial traction.

Continuity into the current hub cycle through sensing, imaging and timing scale-up.

In the current mission hub cycle, Glasgow plays a leading role in QuSIT, the UK hub focused on quantum sensing, imaging and timing for real world use. The stated purpose is to overcome barriers to manufacturing and use at scale and to work closely with industry on deployable systems, carrying forward capability built through QuantIC and earlier sensing and timing programmes.

3. **Device-making capacity that keeps high value work local**

What makes Glasgow strategically distinctive is that hub leadership is backed by nationally significant device-making infrastructure.

- **James Watt Nanofabrication Centre (JWNC):** the University positions JWNC as a leading academic nanofabrication cleanroom that undertakes applied and commercial work alongside research and can run small prototyping and production runs. It also provides capability in superconducting materials and quantum device and circuit fabrication, supported by advanced metrology and low temperature testing.
- **Industrial interface and delivery:** JWNC provides commercial access through Kelvin Nanotechnology which matters because it creates a practical route for companies and public programmes to access process capability and de-risk manufacturing steps inside Scotland.
- **Mazumdar-Shaw Advanced Research Centre (ARC)[63]:** the ARC was designed around cross-disciplinary themes and Quantum and Nanotechnology is one of its named pillars. This matters because it pulls researchers, facilities

[63] University of Glasgow (n.d.) *Research Themes: Quantum and Nanotechnology*. https://www.gla.ac.uk/schools/engineering/research/themes/quantum-technology/

and partners into one place and makes industry engagement easier to execute.

- **Critical Technologies Accelerator (CTA):** A Glasgow City Region Innovation Accelerator–funded programme embedded in the James Watt Nanofabrication Centre that adds dedicated design, test and manufacturing engineering capacity to help industry partners prototype and de-risk photonics, semiconductor and quantum devices, strengthening Scotland's route from lab designs to manufacturable components.
- **Centre for Quantum Technology:** a cross-disciplinary institutional hub bringing together physics, engineering and computer science across quantum computing, imaging and communications, with a visible mandate to train the next generation[64]

4. Quantum computing interface engineering (EPIQC):

Glasgow leads the EPSRC/UKRI-funded Empowering Practical Interfacing of Quantum Computing (EPIQC)[65] programme, targeted at the practical bottlenecks that stop quantum processors becoming usable infrastructure. The work focuses on optical interconnects, wireless control and readout, and cryoelectronics, strengthening Scotland's capability in the control, wiring and integration layer that underpins scalable quantum computing systems.

5. Quantum materials sovereignty:

The University is advancing silicon carbide and lithium niobate thin film on insulators as strategic material platforms to secure sovereign access to high-quality quantum photonic chip fabrication and the electro-optic components and devices. This strand is led jointly by the Quantum Nanophotonics Research Group and a Critical Technologies Accelerator, strengthening Scotland's resilience and sovereignty in quantum materials supply chain and enabling manufacturable, exportable photonic subsystems supported through the PQA grant.

[64] University of Glasgow (n.d.) *Centre for Quantum Technology*. https://www.gla.ac.uk/research/az/quantumtechnology/

[65] UKRI (n.d.) *Empowering Practical Interfacing of Quantum Computing (EPIQC)*. https://gtr.ukri.org/projects?ref=EP%2FW032627%2F1

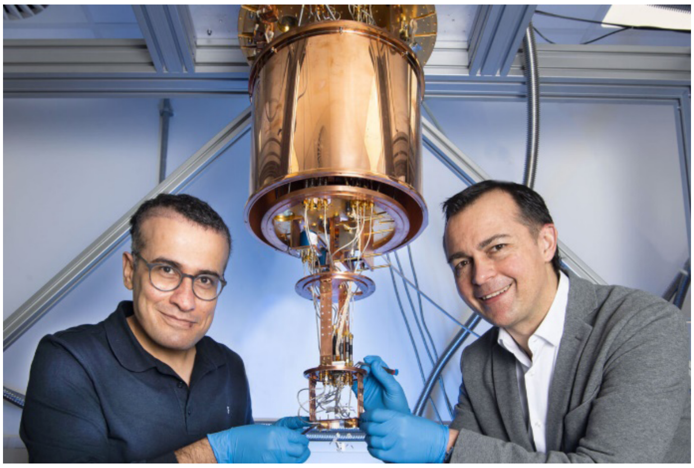


Fig. 4.4: Professor Hadi Heidari (left) and Professor Martin Weides (right) of the James Watt School of Engineering (Image: University of Glasgow).

Fig. 4.3: Mazumdar-Shaw Advanced Research Centre (ARC) at the University of Glasgow.

4.1.2

University of Strathclyde

Strathclyde's value in Scotland's quantum landscape is that it sits closest to the engineering realities that decide whether quantum leaves the lab. It is where photonics, timing assurance, sensing deployments and cryogenic electronics meet system constraints like traceability, reliability, integration and operation in real environments.

The elements that make Strathclyde especially important to workforce and deployment strategy:

1. **Photonics and laser engineering that directly underpins quantum systems**

Strathclyde's Institute of Photonics is an industrially engaged capability base in lasers and optical systems, with explicit collaboration in quantum technologies. This matters for Scotland because many quantum platforms fail to scale not on "quantum theory", but on the quality, stability and manufacturability of photonic subsystems (lasers, optical delivery, photonic packaging, test setups).

2. **Timing and trust-layer infrastructure**

The National Physical Laboratory (NPL) launched the first National Timing Centre innovation node at Strathclyde[66]. This node provides traceable time signals linked to Coordinated Universal Time (UTC), maintained by NPL, with capability that supports quantum and photonics as well as sectors like energy and finance. This matters because infrastructure buyers adopt what they can verify: timing assurance, traceability and measurement confidence are often the deciding factors, not sensitivity claims alone.

3. **Deployment-facing sensing programmes**

Strathclyde has helped deliver a UK-wide network of quantum magnetometers for space weather monitoring[67], installed to provide national coverage and feed operational monitoring led by the British Geological Survey.

[66] University of Strathclyde (2024) *Innovation Node Launched to Drive Development of New Time-Critical Technologies.* https://www.strath.ac.uk/whystrathclyde/news/2024/innovationnodelaunchedtodriveukdevelopmentofnew-time-criticaltechnologies/

[67] University of Strathclyde (2025) *Quantum Technology Strengthens UK Resilience to Space Weather.* https://www.strath.ac.uk/whystrathclyde/news/2025/strathclydequantumtechnologystrengthensukresiliencetospaceweather/

Fig. 4.5: Technology & Innovation Centre at University of Strathclyde.

Fig. 4.6: Launch of a National Timing Centre (NTC) innovation node at the University of Strathclyde in March 2024 (Image: NPL).

4. Cryogenic electronics integration

Strathclyde is collaborating with NPL and industry[68] on the FIRETRACE project, working on the thermal behaviour of cryogenic electronics and how control electronics can operate closer to quantum hardware at very low temperatures. This is a practical scaling problem across several quantum computing approaches and it is also skills-intensive, making it directly relevant to workforce planning. The programme explicitly links to doctoral training in applied quantum engineering.

Photonic capability is a core part of this role, not an add-on. Strathclyde's Institute of Photonics and the **Fraunhofer Centre for Applied Photonics** (based in the Technology and Innovation Centre) strengthen Scotland's ability to translate quantum requirements into lasers, optical systems and photonic components with industrial pathways and delivery culture. This is one of the clearest routes from research strength to manufacturable subsystems and customer-ready platforms.

Strathclyde's strategic relevance also extends into mission-led and security-facing collaboration. AWE Nuclear Security Technologies has publicly stated that the **Quantum Centre for Nuclear Defence and Security**[69] is led by Strathclyde, linking Scottish capability into high-assurance R&D agendas where validation standards and systems engineering are non-negotiable.

Strathclyde positions quantum as a named cluster within its Technology & Innovation Zone, explicitly framed around translating R&D into industrial application. This strengthens Scotland's deployment story because it provides an institutional vehicle for co-location, challenge-led collaboration and repeatable routes for industry to engage.

[68] University of Strathclyde (2025) *FIRETRACE: Addressing Quantum Computing Challenges.* https://www.strath.ac.uk/whystrathclyde/news/2025/firetrace/

[69] AWE (2025) *Quantum Centre for Nuclear Defence and Security Launched.* https://www.awe.co.uk/2025/11/awe-marks-international-year-of-quantum-science-and-technology/


Fig. 4.7: Fraunhofer Centre for Applied Photonics (Image: Fraunhofer).

Fig. 4.8: The University of Edinburgh.

4.1.3

University of Edinburgh

Edinburgh's strategic role in Scotland's quantum architecture is to make quantum computing useful, testable and comparable in real settings. It does this by coupling (1) a dedicated use-case translation function with the National Quantum Computing Centre (NQCC) and industry, (2) the UK's most mature national HPC delivery capability through EPCC, and (3) a workforce pipeline built around quantum informatics, verification, benchmarking and research software engineering.

What Edinburgh uniquely contributes

1. A formal use-case translation function, tied directly to the NQCC

The **Quantum Software Lab (QSL)** is structured to work alongside the NQCC to identify, develop and validate real-world use cases with NQCC applications engineers and industry partners[70]. This moves quantum computing beyond "algorithm novelty" into measurable workflows: problem definition, baseline comparison, performance evaluation and delivery against an end-user constraint.

[70] NQCC (n.d.) *Quantum Software Lab: Overview and Remit.* https://www.nqcc.ac.uk/infrastructure/quantum-software-lab/

2. Global coordination of the software ecosystem, not just local research output

In February 2026, Edinburgh announced the **Quantum Software Alliance**, positioning the University as a convening point for the global community that must mature software, benchmarking practice and application evidence alongside hardware[71]. For Scotland, this increases international visibility for roles that directly determine adoption timelines, including workflow engineering, error mitigation, verification and benchmarking.

[71] University of Edinburgh / EPCC (2026) *Quantum Software Alliance Announcement.* https://www.ed.ac.uk/news/global-network-puts-spotlight-on-quantum-software

Fig. 4.9: Sir Peter Knight, Prof. Jane Hillston, Michael Cuthbert, Prof. Iain Gordon, Prof. Elham Kashefi and Roger McKinlay at the launch of the Quantum Software Lab (Image: University of Edinburgh).

3. National compute infrastructure that makes "hybrid quantum-classical" credible in practice

Edinburgh is home to EPCC, which operates ARCHER2[72], the UK's National High Performance Computing service. This is strategically important because most near-term quantum value will be delivered through hybrid workflows that combine classical HPC with quantum accelerators, plus rigorous performance baselining. Edinburgh is one of the few places in the UK where quantum software work can sit alongside the operational reality of national-scale compute delivery, user support and training.

Edinburgh has also positioned itself as the host for the UK's planned £750m national supercomputer, reinforcing the University's role as a national compute anchor. Regardless of the final system specification, the direction is clear: Edinburgh is where the UK is concentrating high-end computing operations and associated skills, which strengthens Scotland's ability to build quantum-HPC workforce depth rather than treating quantum as a standalone niche.

[72] University of Edinburgh (n.d.) *University Set to Host £750m National Supercomputer.* https://www.ed.ac.uk/news/university-set-to-host-ps750m-national-supercomputer

4. An industry-facing software and data innovation layer that supports adoption pathways

Edinburgh has a practical interface for this through its wider innovation infrastructure, including the Bayes Centre for industry co-location and translation in data and computing, and the **Edinburgh International Data Facility (EIDF)**, a research cloud and data service built and operated by EPCC.

Edinburgh has also launched an industry-linked **Quantum and AI software centre** with a focus that explicitly includes quantum computing, reinforcing the "applications pull" that Scotland needs to complement its hardware strengths[73].

5. National hub integration (QCI3)

Edinburgh (via EPCC and the School of Informatics/QSL community) is a partner in the EPSRC Hub for **Quantum Computing via Integrated and Interconnected Implementations (QCI3)**, contributing software, applications and performance/validation work into the UK's core quantum-computing mission programme.

[73] University of Edinburgh, Bayes Centre (n.d.) *Quantum and AI Centre Launched with Cisco.* https://bayes-centre.ed.ac.uk/media-centre/news/ai-news/quantum-ai-centre-launched-with-cisco

Fig. 4.10 ARCHER2 - the UK's National High Performance Computing system - facilitates world-class science for UK researchers (image: University of Edinburgh).

4.1.4

Heriot-Watt University

Heriot-Watt's strategic role in Scotland's quantum architecture is clear and specialised: it leads the UK's national effort on quantum networking and the practical steps needed to move from point-to-point demonstrations to interoperable networks that can be deployed, operated and assured.

Through the Integrated Quantum Networks (IQN) Hub[74], Heriot-Watt is not just advancing components or theory. It is coordinating the technologies, protocols and standards required for secure quantum communications across fibre and space links, alongside national labs and a large industrial base.

1. UK hub leadership focused on deployment, not isolated breakthroughs

Heriot-Watt leads **the IQN Hub**, one of the five UK quantum technology research hubs backed through the UK National Quantum Technologies Programme. The IQN remit is explicitly "network scale": distributing entanglement across local and national networks, extending to satellite-linked architectures, and developing the **protocols and industry standards needed for deployment at scale**[75].

[74] UK Government (2025) *Over £100 Million Boost to Quantum Hubs to Develop Life-Saving Blood Tests and Resilient Security Systems.* https://www.gov.uk/government/news/over-100-million-boost-to-quantum-hubs-to-develop-life-saving-blood-tests-and-resilient-security-system

[75] Heriot-Watt University (2025) *New UK Quantum Hub Launches to Pioneer Secure Networks and Advance the Quantum Internet.* https://www.hw.ac.uk/news/2025/new-uk-quantum-hub-launches-to-pioneer-secure-networks-and-advance-the-quantum-internet

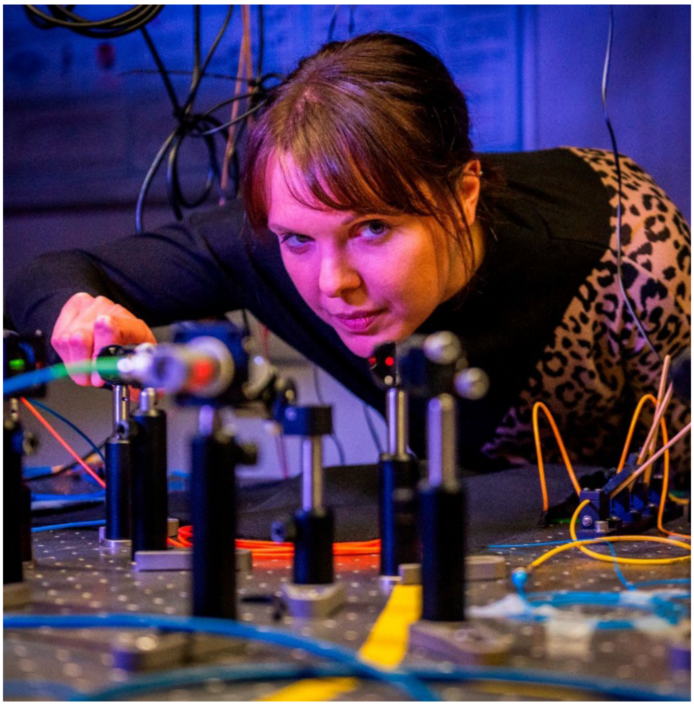


Fig. 4.11: The Integrated Quantum Networks Hub at Heriot-Watt (Image: Heriot-Watt University).

2. A space-linked network test facility that forces real engineering decisions

IQN has brought a critical piece of infrastructure into Scotland: t**he Hub Optical Ground Station (HOGS)** at Heriot-Watt's Edinburgh Research Park, opened as a £2.5m facility to support quantum-secure optical links and space-linked networking experiments[76].

Satellite linkage is not a "future add-on" for quantum networks. It is the route to long-distance connectivity, and it introduces the hard constraints that shape

[76] IQN Hub (2025) *Open for Business: Heriot-Watt University Unveils New £2.5M Quantum-Enabled Optical Ground Station.* https://iqnhub.org/open-for-business-heriot-watt-university-unveils-new-2-5m-quantum-enabled-optical-ground-station/

Fig. 4.12: Development of quantum communication at Heriot-Watt's Institute of Photonics and Quantum Sciences (IPaQS).

Fig. 4.13: Researchers from the Integrated Quantum Networks hub at a special parliamentary reception at the Scottish Parliament (Image: IQN).

deployable systems (optical terminals, pointing, atmospheric effects, verification and operations).

3. **The photonics and quantum communications base that makes networks buildable**

Heriot-Watt's **Institute of Photonics and Quantum Sciences (IPaQS)** anchors the device and photonics layer behind the networking mission, including quantum communication and networking as a stated research focus.

Scalable networks depend on engineered photonic sources, detectors, interfaces and system integration, not just protocols. Scotland benefits when that capability is concentrated locally rather than imported as black-box subsystems.

4. **A national partnership structure that is designed for interoperability**

IQN brings together a wide set of UK universities plus national laboratories including NPL and RAL Space, alongside a large industrial partner base. The winning architectures will be the ones that can coexist with classical telecoms infrastructure, integrate timing and synchronisation, and demonstrate repeatable performance across nodes built by different teams.

Heriot-Watt anchors Scotland's "secure communications and networking" pillar at UK scale. It strengthens Scotland's position in a capability area with direct national security and critical infrastructure relevance, and it gives Scotland a practical asset base that can attract partners, trials and supply-chain work.

Fig 4.14: University of St Andrews.

4.1.5

University of St Andrews

St Andrews strengthens Scotland's quantum stack in two places where long-term advantage is built: quantum materials and quantum optics/quantum information. It also carries a clear signature: specialist infrastructure and collaborations that bring global teams into Scotland.

1. **Centre for Designer Quantum Materials (CDQM)**: CDQM[77] is St Andrews' flagship capability for turning quantum materials from quantum phenomenon into **engineered platforms**, combining precision synthesis, atomic-scale measurement and predictive theory to design materials whose quantum behaviour is controllable and reproducible - full-stack quantum materials capability in one place.
2. **Ultra-low vibration facility:** a dedicated ultra-low vibration building used for atomic-scale measurement work (the kind of specialist environment that attracts international collaboration because it is hard to replicate) and with access to cryogenic STM spectroscopy alongside supporting measurement platforms and characterisation capability[78].

[77] Centre for Designer Quantum Materials (n.d.) *Centre Homepage*. https://www.quantummatter.co.uk/

[78] University of St Andrews (n.d.) *Ultra-Low Vibration Facility*. https://wahl.wp.st-andrews.ac.uk/ultra-low-vibration-facility/

3. **Cleanroom fabrication facilities:** the School of Physics & Astronomy lists cleanroom capability spanning **electron-beam lithography** and **photonic nanofabrication** alongside device-oriented fabrication capability[79].

4. **Photonics Innovation Centre (PIC):** a dedicated, application-facing photonics facility with multiple development labs and a **Class-1000 cleanroom** plus in-house technical support and diagnostic equipment for prototyping and testing[80].

[79] University of St Andrews, School of Physics & Astronomy (n.d.) *Facilities*. https://www.st-andrews.ac.uk/physics-astronomy/research/facilities/

[80] University of St Andrews (n.d.) *Photonics Innovation Centre: Facilities*. https://www.st-andrews.ac.uk/pic/facilities.htm

Fig. 4.15: Opening of a state-of-the-art centre for Designer Quantum Materials at the University of St Andrews, 2016 (Image: St Andrews).

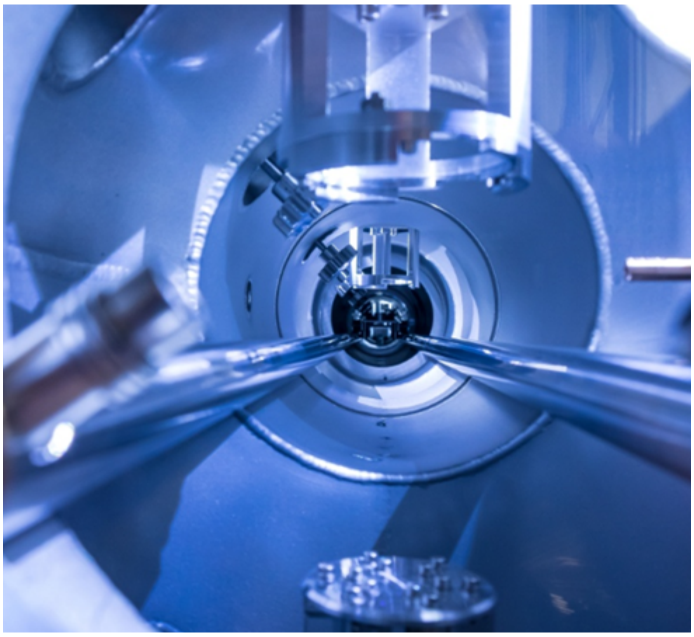


Fig. 4.16: Centre for Designer Quantum Materials (Image: University St Andrews).

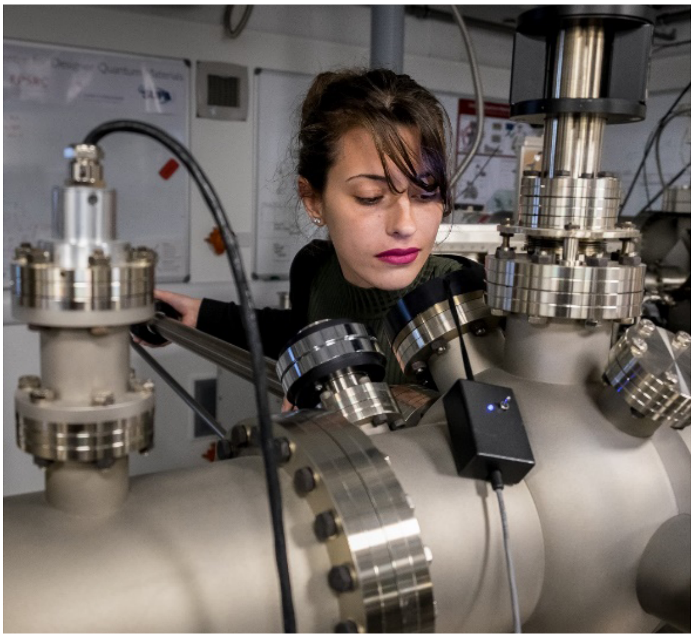


Fig. 4.17: School of Physics and Astronomy at the University of St Andrews (Image: St Andrews).

5. **EU Quantum Flagship footprint (quantum light sources):** the PhoG activity positions St Andrews inside the European quantum technology ecosystem around non-classical light source development[81].

6. **EPR facility:** pulsed and continuous-wave EPR capability in X, Q and W bands (relevant to spin physics and materials characterisation that feeds quantum device understanding).

Taken together, **Scotland's universities form a complete and credible quantum pipeline**. They span frontier science through designer materials, photonics and electronics device fabrication, timing and measurement assurance, quantum networking and secure communications, software and use-case validation, and national-scale compute that enables hybrid workflows. This breadth is not academic variety for its own sake. It is the practical base that lets Scotland move ideas into components and then into deployable systems while keeping key capabilities local.

Continued policy support for these university-led infrastructures and programmes is one of the most direct ways to de-risk scale-up to higher TRLs, attract industrial co-investment, and build sovereign capability in the parts of the stack that are hardest to buy in later. Most importantly, universities are the primary workforce engine. They train the engineers, technicians and applied scientists who will staff Scotland's quantum economy, and in this context workforce is gold.

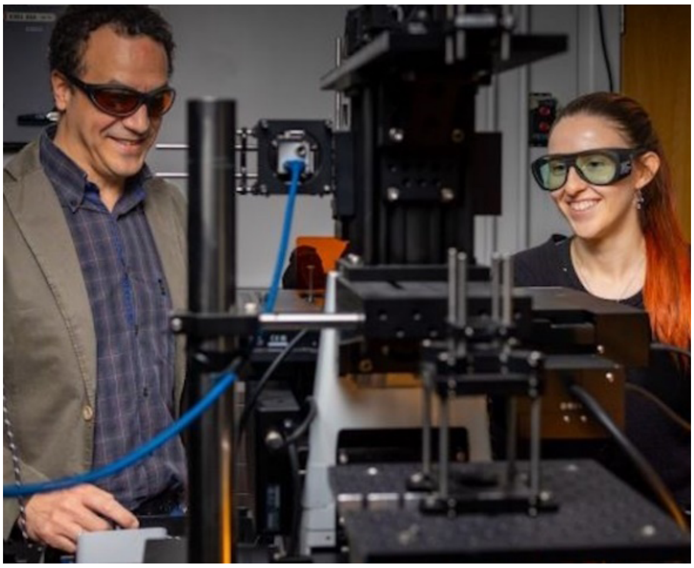


Fig. 4.18: Andrea Di Falco, Professor of Nanophotonics with researcher at the University of St Andrews (Image: University St Andrews).

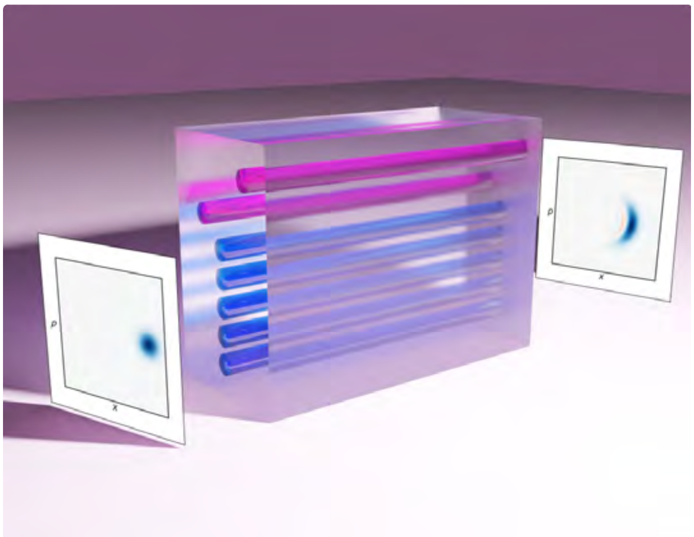


Fig 4.19: EU Flagship Quantum Technologies: Sub-Poissonian Photon Gun (PHoG) by Coherent Diffusive Photonics (Image: St Andrews).

[81] University of St Andrews (n.d.) *PhoG Project*. https://www.st-andrews.ac.uk/~phog/

4.2
Scotland's Senior Academic Workforce

Scotland's academic quantum workforce functions as a high-throughput talent engine[82], anchored by a strong senior cohort and a substantial early-career research bench that collectively sustains continuity, credibility and technical momentum across the ecosystem. The depth of Professor and Reader representation provides stable leadership and long-horizon capability building, while the large postdoctoral and research staff layer is the practical delivery backbone, driving day-to-day experimentation, device iteration and cross-domain integration.

What makes this workforce profile strategically valuable is not only its scale but its composition: it supports rapid cycle time in research and enables Scotland to remain visible across multiple quantum domains without over-reliance on a small set of individuals. At the same time, the relatively small footprint of formal leadership and management roles, alongside limited mapped admin and support capacity, indicates a specific scaling lever rather than a systemic weakness.

As Scotland's activity shifts toward higher-TRL collaboration and deployment-facing programmes, strengthening professional operations, programme management and technical support roles within the academic environment will protect research productivity, improve facility uptime and make it easier for industry partners to engage without friction, ensuring the talent engine continues to convert academic strength into workforce-ready capability.

This concentration creates real global visibility, but it also creates a practical dependency risk: if a capability area is over-reliant on one centre, Scotland's national capacity can be weakened by leadership churn, funding shocks or global recruitment pressure.

The Scottish Universities Physics Alliance (SUPA) serves as a vital instrument for this coordination. By pooling physics research and postgraduate education across eight universities, SUPA facilitates collaboration, supports shared access to major research facilities, and enhances the quality and breadth of graduate training. It acts as a cohesive force, amplifying the collective impact of Scotland's distributed academic strengths.

[82] Note: This analysis reflects the senior academic workforce (faculty, research staff and equivalent roles) and excludes PhD students.

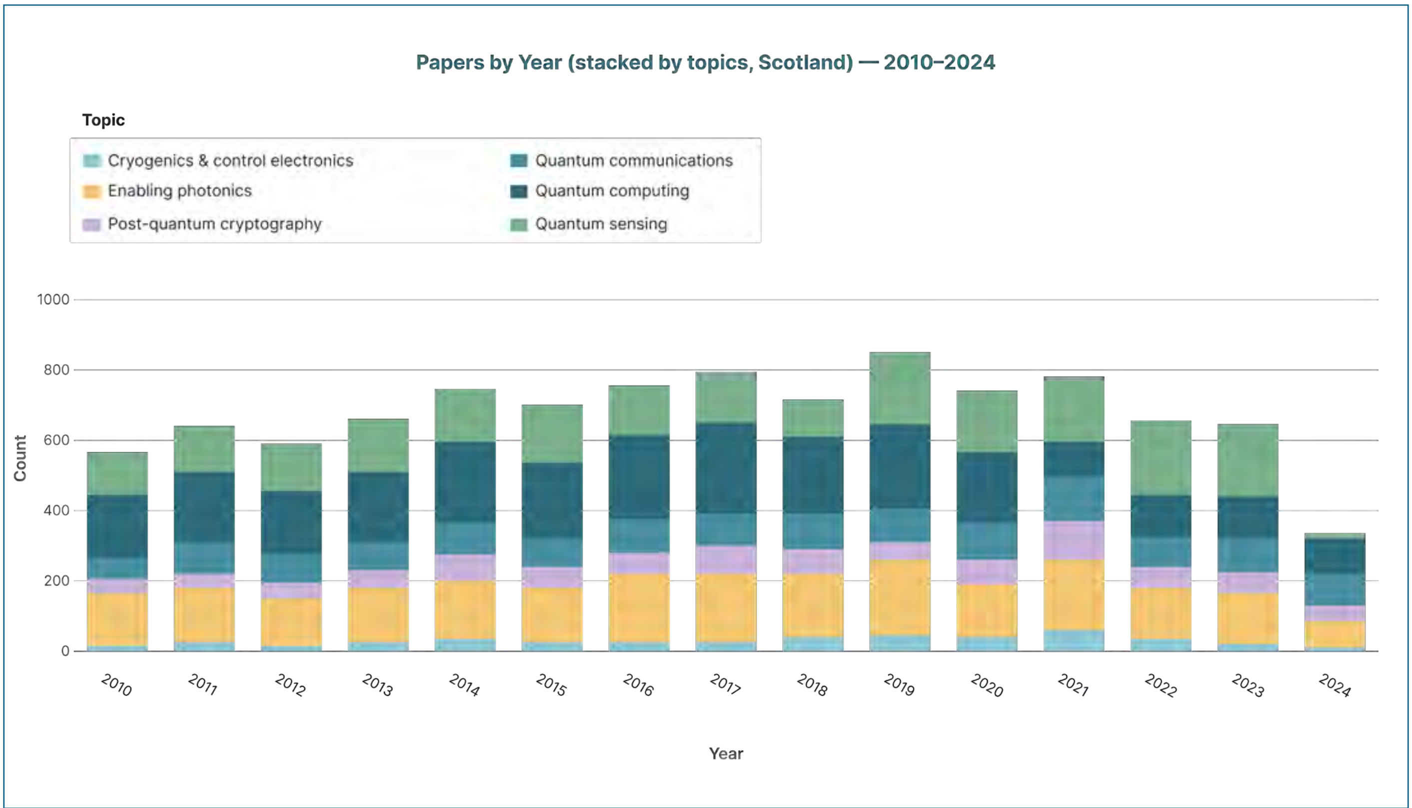


Fig. 4.20: Scotland's quantum research output by year, stacked across key topic areas (2010–2024). The sustained, multi-topic publication base shows breadth across sensing, computing, communications, photonics-enablement, post-quantum cryptography and cryogenics and control electronics, indicating that Scotland has established a foundational footprint across the core domains needed to support end-to-end quantum capability.

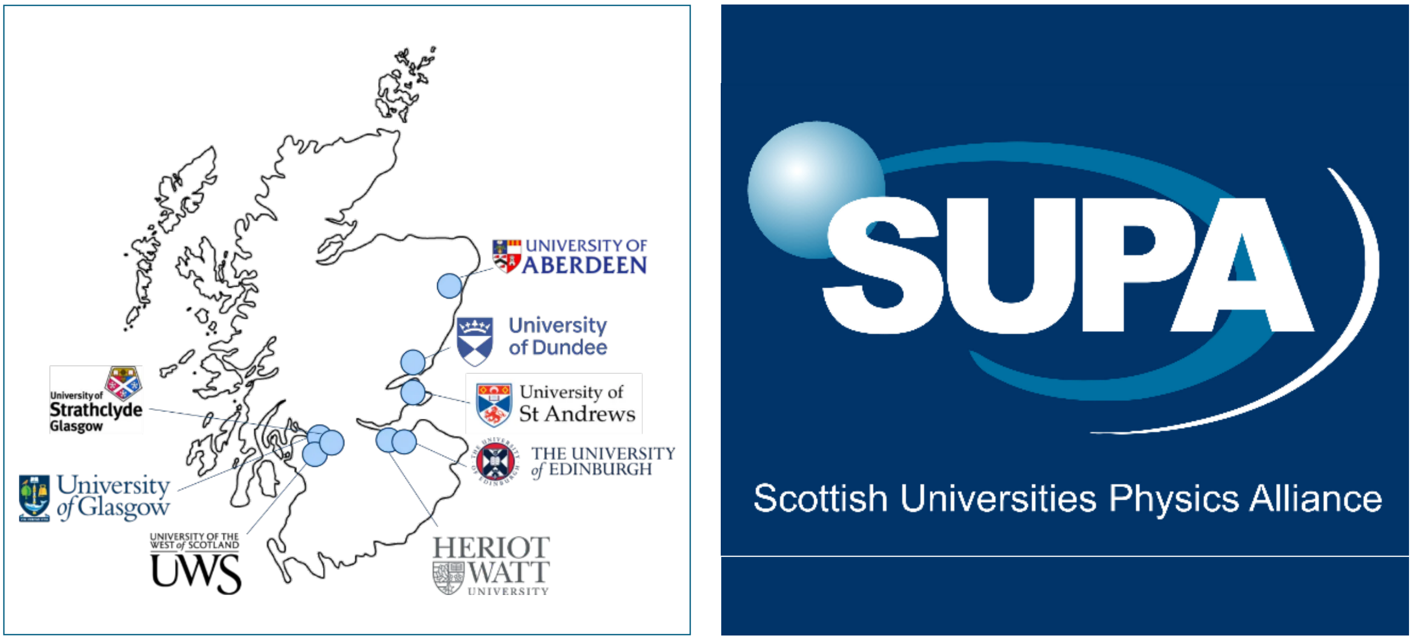


Fig. 4.21: Members of The Scottish Universities Physics Alliance (SUPA, www.supa.ac.uk).

SUPA is governed by an executive committee made up of representatives from each partner university plus the operations manager, setting strategic direction and maintaining strong links with SUSSP and SUPA associate members; its activity is organised into themes such as astronomy & space sciences, condensed matter & materials sciences, energy, nuclear physics, particle physics, photonics, plasma physics, physics & life sciences, physics education research and quantum technologies, each led by a theme leader who drives collaboration across institutions, while postgraduate training is coordinated through a graduate school committee with a member from each university reviewing courses, and day-to-day delivery is managed by the operations manager supported by SUPA staff[83].

[83] Scottish Universities Physics Alliance (n.d.) *About SUPA*. https://www.supa.ac.uk/about_supa/about_supa.php

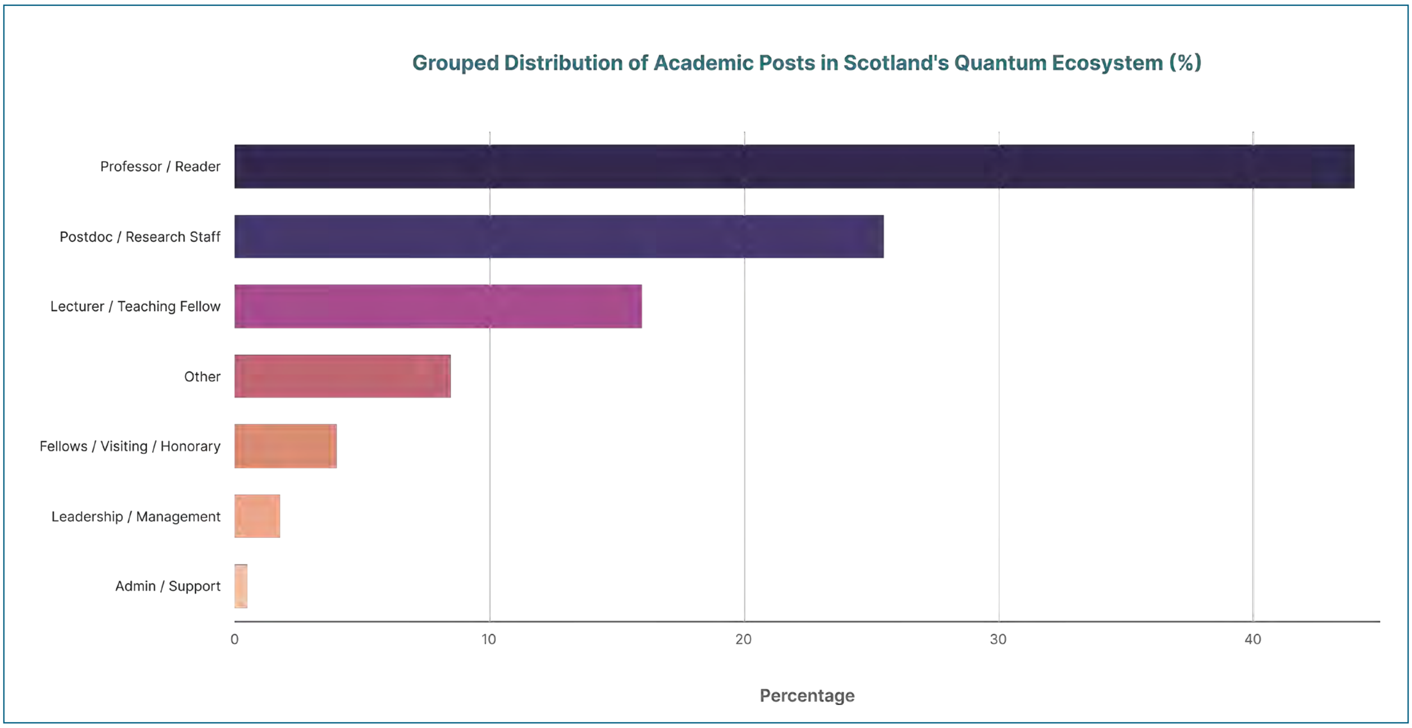


Fig. 4.22: Breakdown of Scotland's senior academic quantum workforce by post category, highlighting a substantial senior faculty layer and a large postdoctoral and research staff bench that underpins delivery capacity.

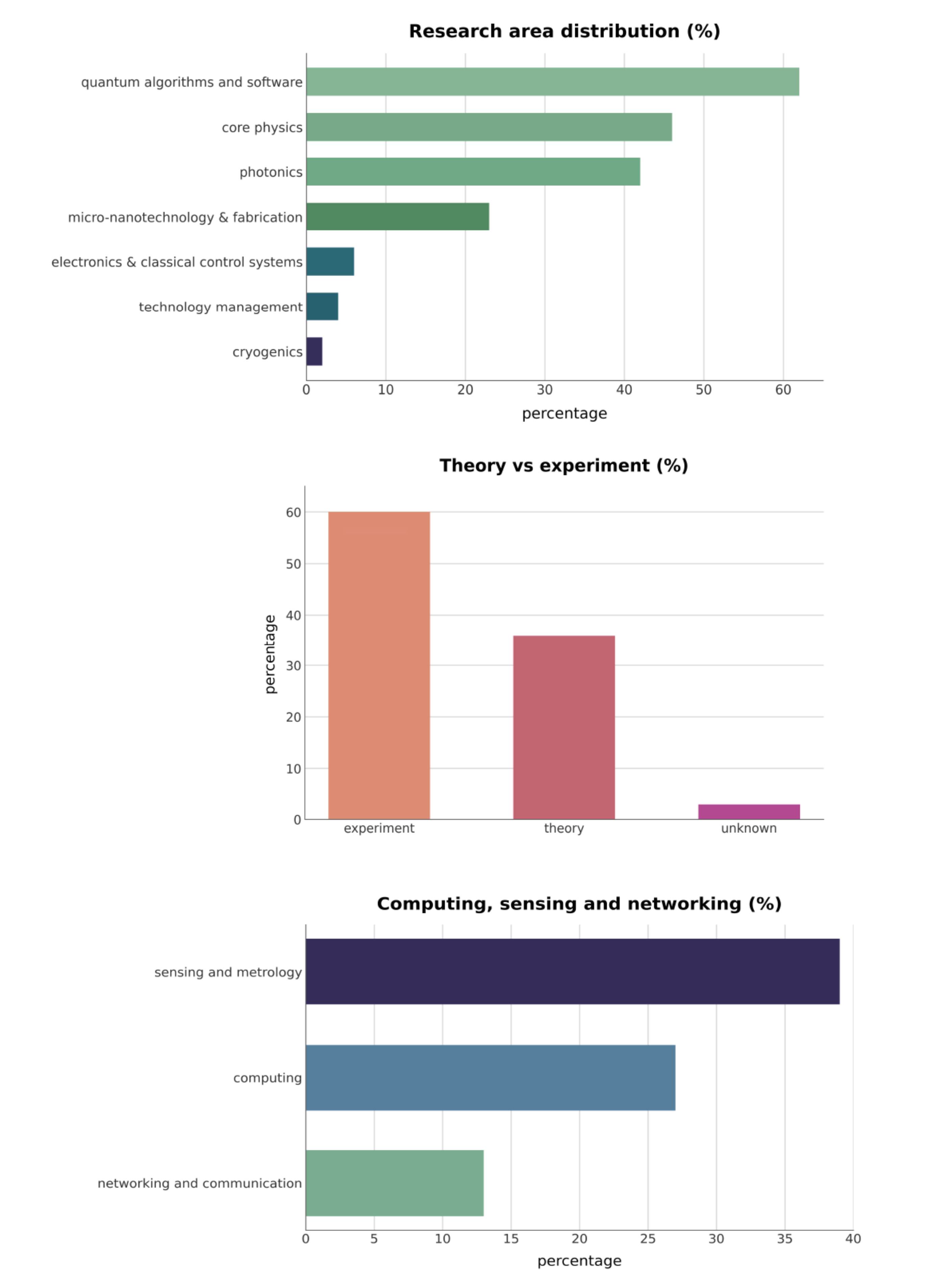


Fig. 4.23: (Top) Distribution of Scotland's senior academic quantum workforce by research area, theory vs experiment orientation and application emphasis (computing, sensing and networking). The profile indicates strong representation in quantum algorithms and software, core physics and photonics, with a clear experimental weighting and a pronounced strength in sensing and metrology.

4.3

Future-proofing the quantum workforce

Scotland's quantum sector is moving from research excellence to deployment, and that shift changes the skills profile the market needs. Employers are no longer only hiring PhD specialists. They need MSc-level talent that can operate across the interface between physics and engineering: photonics and device fundamentals, measurement and control, data analysis and modelling, and the practical discipline of building reproducible experiments and prototypes.

This is exactly where Masters programmes in quantum technologies become strategically valuable. Scotland is well placed to deliver this pipeline because its universities sit on top of the right infrastructure and missions: nanofabrication and component prototyping, photonics and laser engineering, timing and assurance capability, quantum networking leadership, and software and use-case validation connected to national compute.

Programme Title	Lead Institution	Key Modules
MSc Quantum Technology	University of Glasgow	Quantum Materials, Quantum Electronic Devices, Advanced Data Analysis
MSc Quantum Technology	University of Strathclyde	Topics in Photonics, Laser & Nonlinear Optics, Physics Skills (Python/Data)
MSc Quantum Technology	Heriot-Watt University	Nanophotonics, Quantum Lab & Programming, Photonic Sensors
MSc Applied Photonics (EngD Pathway)	Heriot-Watt / Glasgow	Laser Material Processing, Optical Communications, Biophotonics
MSc Data Science	University of Aberdeen	Relativistic Quantum Chaos, Complex Networks, Big Data: Compressive Sensing
Quantum Informatics options within taught MScs	University of Edinburgh	Introduction to Quantum Computing and Programming, Quantum Cyber Security
MSc/PgDip Photonics	University of Strathclyde	Photonic materials, quantum optics and quantum information technology

Table 4.1: MSc Programmes in quantum technologies.

Programme Title	Core Scottish Partners	Core Focus
CDT in Applied Quantum Technologies (AQT)	Strathclyde, Glasgow, Heriot-Watt	Sensing, computing/simulation, communications with strong industry cocreation
CDT in Quantum Informatics	Edinburgh, Strathclyde, Heriot-Watt	Quantum software, architectures, hardware–software interaction, application analysis
CDT in Use-Inspired Photonic Sensing and Metrology (Applied Photonics)	Heriot-Watt, St Andrews, Strathclyde, Glasgow, Edinburgh	Photonic sensing + metrology with heavy EngD (industry-hosted) stream
CDT in Algebra, Geometry and Quantum Fields (AGQ)	Glasgow, Edinburgh, Heriot-Watt	Mathematical physics foundations that feed quantum computation, cryptography and modelling

Table 4.2: Specialised doctoral programs for quantum technologies.

PhD talent: the skills bedrock behind quantum scale-up

Doctoral researchers are the talent base that keeps Scotland competitive in quantum because the work is fundamentally specialist and research-led. Quantum founders are disproportionately drawn from advanced training because building credible quantum products requires deep technical judgement across physics, materials, devices and software, not just business execution[84].

[84] OECD (2025) *Mapping the Global Quantum Ecosystem*. OECD: Paris. https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/12/mapping-the-global-quantum-ecosystem_47891dd2/20251217-0001.pdf

That pattern shows up clearly in founder profiles: quantum firms are far more likely to be founded by people with PhDs than firms in general, reflecting how strongly the sector depends on frontier research, hard-won experimental know-how and the ability to translate novel effects into engineered components and systems.

For Scotland, this reinforces a simple point: sustained investment in doctoral training and research infrastructure is not just supporting publications, it is building the skills, IP and future founders that will anchor high-TRL scale-up and the local quantum economy.

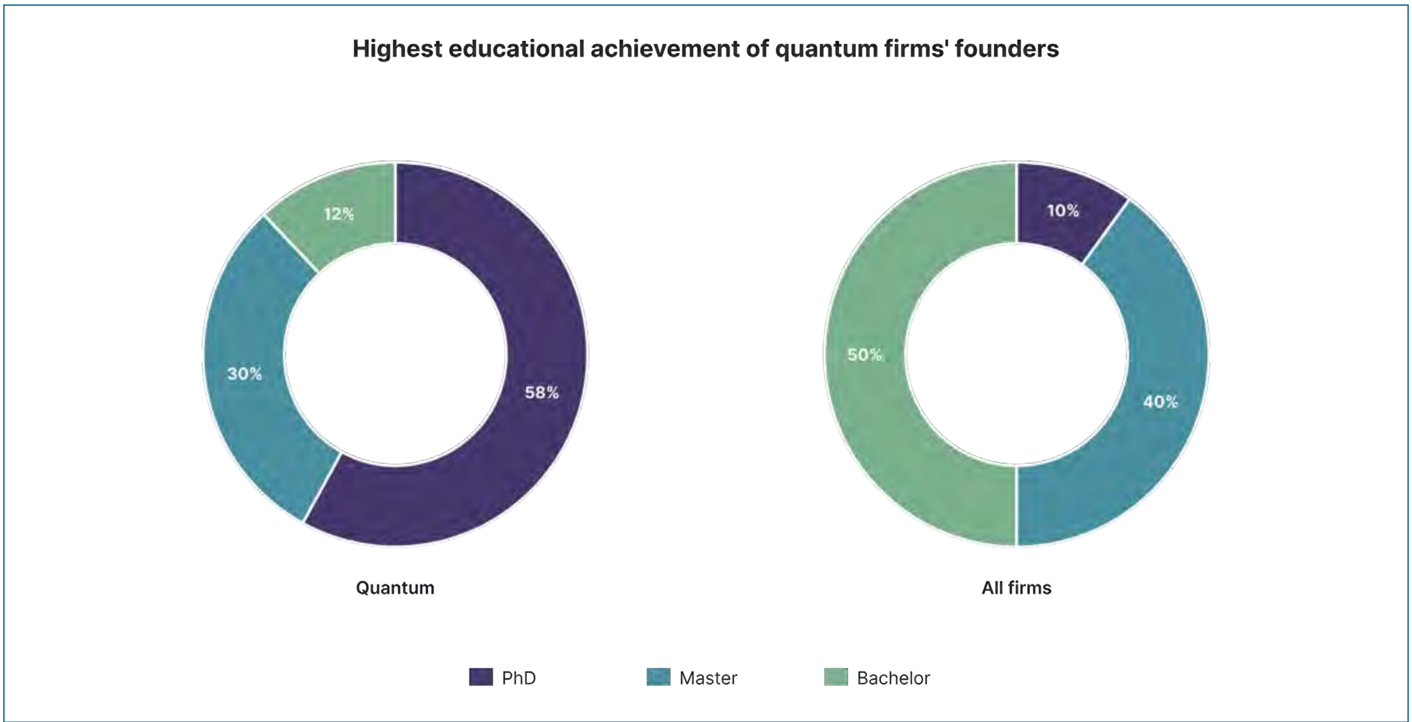


Fig. 4.24: Highest educational achievement of founders globally: quantum firms show a much higher concentration of PhD-trained founders (58%) compared with all firms (10%), highlighting the sector's reliance on highly specialised, research-led talent.

4.4
Industry demand vs. supply

Scotland's skills gap is often discussed as if it is a shortage of "quantum people". The demand signal in this chapter is more specific and more useful. Industrial demand clusters into four role families that map to the actual conversion chain from lab to deployment: hardware and fabrication engineers, software and algorithms engineers, enabling technical support roles, and commercial translation roles.

The highest-leverage point for Scotland is that these roles are strongly aligned with capabilities Scotland already has or can credibly scale. Photonics engineers, nanofabrication engineers, cryo-electronics engineers and packaging engineers sit directly on Scotland's enabling base and infrastructure strengths. The constraint is not capability in principle. It is workforce availability at the right levels, at the right TRLs, in sufficient numbers.

Industry demand is hybrid: "quantum skills" plus enabling skills

The online job-posting signal shows growth in both "quantum skills" and "enabling skills", but the pattern is not a simple upward line. Hiring intensity surged in the 2022 period, then normalised, with quantum-skill demand remaining consistently higher and showing renewed strength through 2024–2025 (Fig. 4.25). The more useful takeaway is the shape of demand: employers are recruiting for quantum roles that sit inside broader engineering and software functions. In other words, quantum job growth is being pulled forward by roles that can ship systems, not only by roles that can publish results.

Enabling skills that dominate hiring are rising, not shrinking

When you strip demand down to specific enabling skills, the hierarchy is clear and it maps directly to Scotland's strengths. **Photonics is the dominant enabling skill** required in quantum-related job postings and its share rises materially from the 2021–2022 period to 2023–2024 (Fig. 4.26).

Semiconductors and lasers form the next tier, with **ultra-high vacuum** also increasing, signalling growing demand for the practical environments and process disciplines needed for device development and test. These are not "nice-to-have" competencies. They are the day-to-day foundation of quantum sensing, photonic quantum, many hardware platforms and the supply chain that supports them. Scotland has a base to cover all these enabling skills and should invest more in that as it itself is an enabling ecosystem.

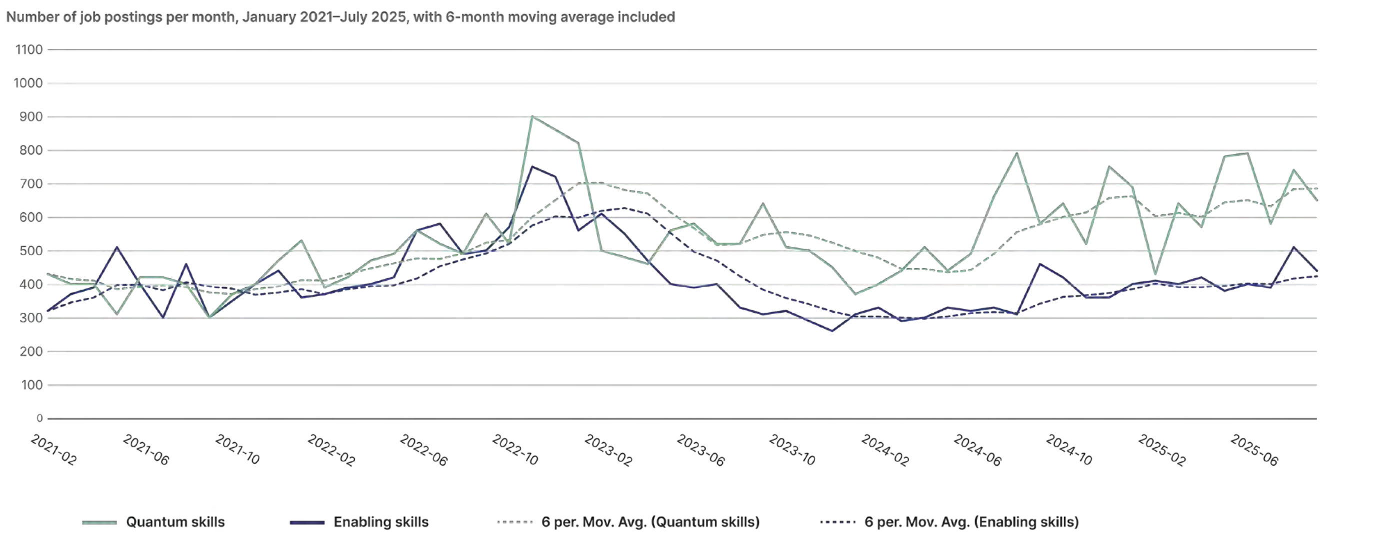


Fig. 4.25: Monthly quantum-related online job postings globally (Jan 2021–Jul 2025) for quantum skills and enabling skills with 6-month moving averages. Demand is sustained and increasingly hybrid, with quantum roles pulling strongly on adjacent engineering capability. (OECD data)

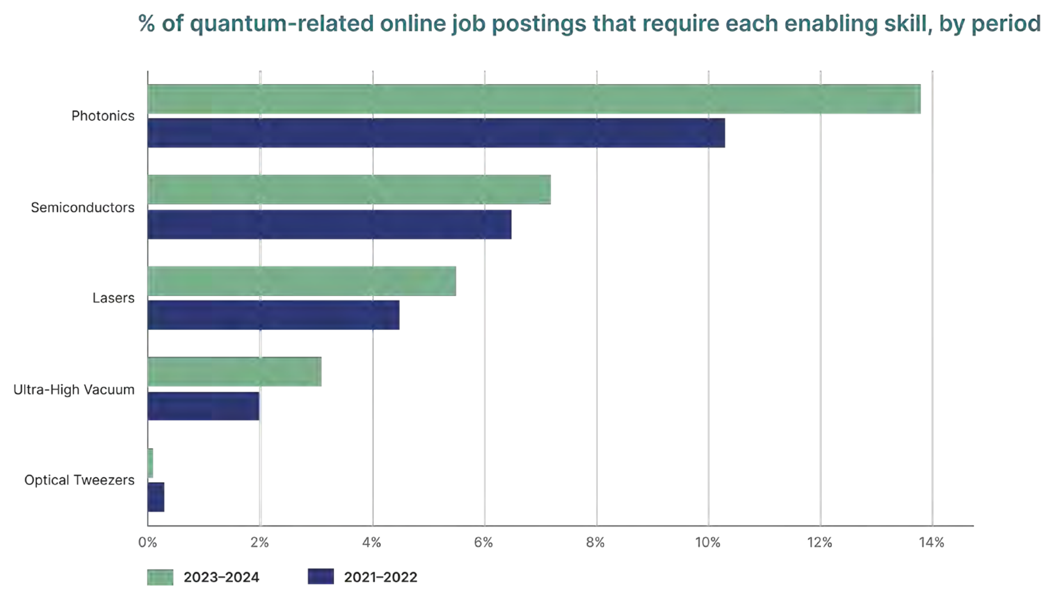


Fig. 4.26: Share of quantum-related online job postings requiring key enabling skills by period. Photonics leads and grows, followed by semiconductors and lasers, with ultra-high vacuum increasing as quantum work moves closer to device and system build-out.

Education level shapes the skills mix, so Scotland needs multiple training levers

The education-segment view makes the pipeline design implication explicit (Fig. 4.27). PhD-level postings strongly concentrate around research and quantum physics depth, as expected. Masters-level postings still require quantum content, but they also pull strongly on software, modelling, analysis and systems skills. Bachelor-level postings show even stronger demand for broadly deployable skills such as computing, programming and communication, which are often the entry route into technician, engineering and support roles that keep facilities and projects moving. This is exactly why apprenticeships and conversion pathways matter. Scotland can expand capacity faster by training people into **enabling roles** (photonics, semiconductors, lasers, vacuum, test, RSE) while protecting and growing the doctoral base that drives platform advantage.

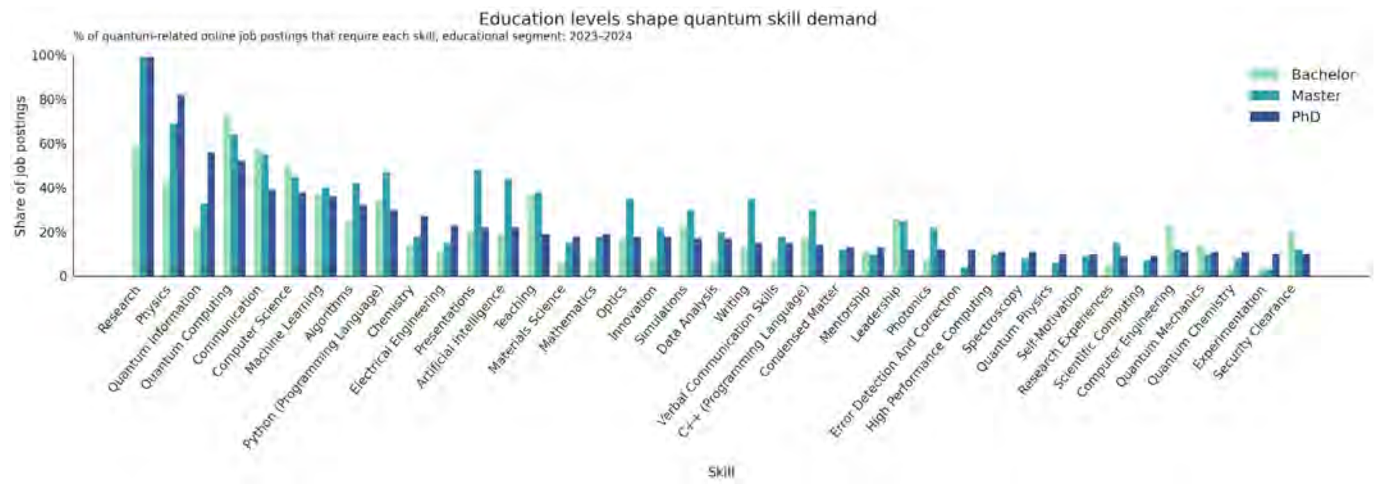


Fig. 4.27: Quantum-related job postings by required skill and education segment (2023–2024). Demand splits into distinct profiles across Bachelor, Master and PhD levels, reinforcing the need for a tiered training strategy rather than a single-track quantum specialist model.

Building job-ready quantum talent: education-to-industry pathways

The pathways into quantum workforce[85] are not linear, and this is exactly why Scotland needs multiple entry routes. Most people do not move straight from a Bachelor's degree into a quantum job. They typically pass through a Master's or PhD, then add specific quantum training (short courses, lab-based modules, CDT-style taught blocks) and crucially industrial experience before they become "deployable" hires.

The diagram also reflects a second reality: research and academia remain a major feeder into industry, especially through postdoctoral roles, because the sector still relies on specialised experimental judgement and platform-building skills. For Scotland, the implication is practical: strengthen MSc and CDT pipelines, but also expand conversion training and industry placements so enabling talent can enter from multiple education levels and move into jobs without waiting for a full PhD cycle.

[85] Kaur, M. and Venegas-Gomez, A. (2022) 'Defining the quantum workforce landscape: a review of global quantum education initiatives', *Opt. Eng.*, 61(8), 081806. https://doi.org/10.1117/1.OE.61.8.081806

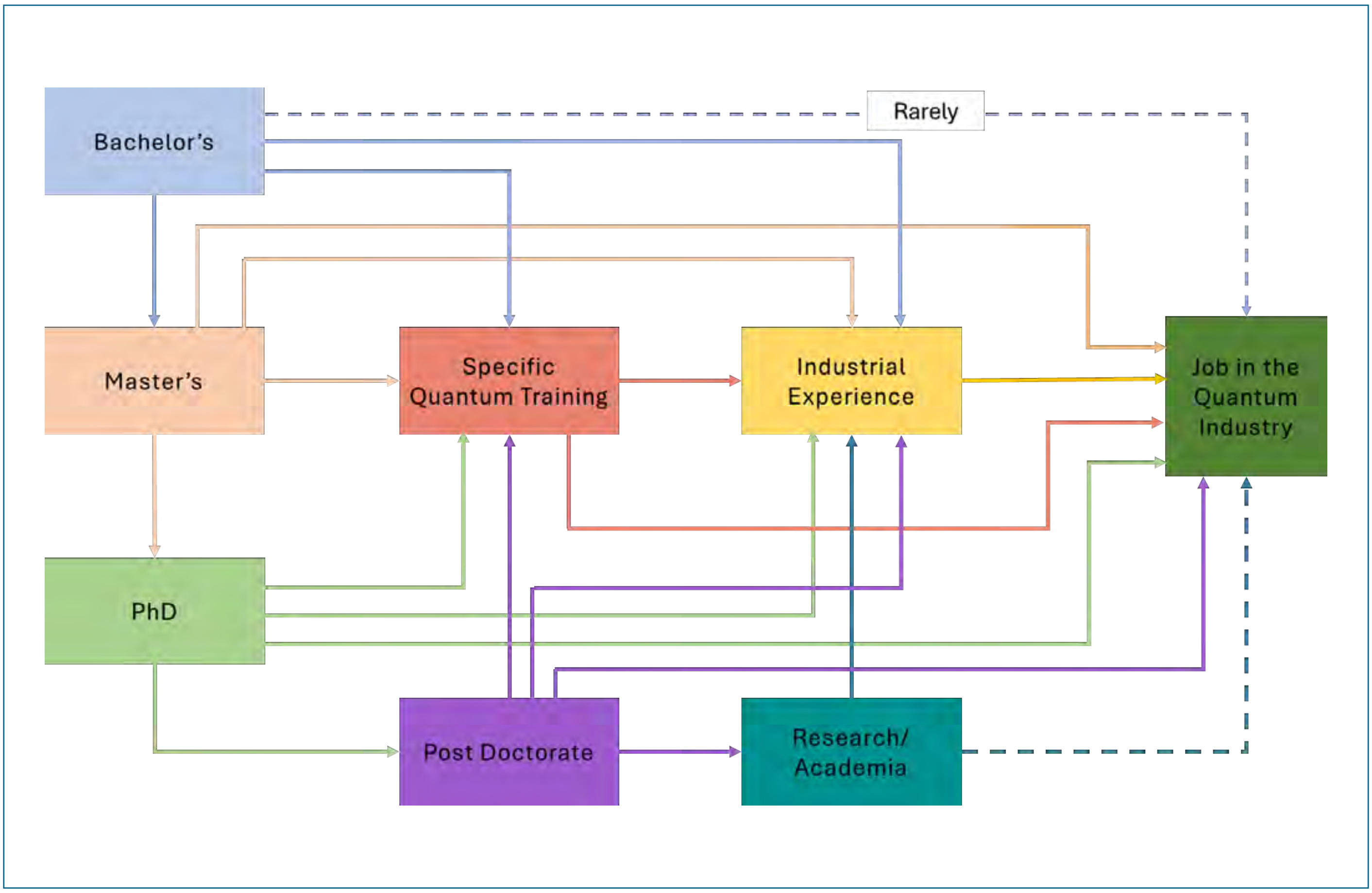


Fig. 4.28: Typical routes into quantum industry roles. Direct entry from bachelor's is rare. Most pathways combine postgraduate study with specific quantum training and industrial experience, route as major feeders into industry. (QURECA, https://www.qureca.com/a-review-of-quantum-education-initiatives-worldwide/)

4.5

The quantum conversion chain

Scotland's quantum advantage starts in world-class research, but it only becomes economic value when that research is converted into components, integrated into systems, and validated well enough for adopters to buy. That journey is not a single jump in TRL. It is a sequence of distinct steps, each with its own constraints and workforce profile (Fig. 4.29).

At the early stages (TRL 1–3), the priority is discovery and proof: universities, RTOs and industry teams generate new capability using shared assets such as nanofabrication, quantum hardware testbeds, quantum platforms, HPC and specialist service labs. The workforce here is research-heavy: doctoral researchers, postdocs, specialist facility staff and research software engineers who keep instruments, cleanrooms and compute usable at pace.

By the mid stages (TRL 4–6), the job changes. The challenge is no longer "does it work" but "can it be engineered and reproduced": device yield, test repeatability, reliability under field conditions, documentation, supply chain options, and integration with non-quantum subsystems. This is where the conversion layer becomes decisive, and it is also where Scotland's skills gaps become binding: systems engineers, packaging and test engineers, photonics and semiconductor process talent, cryogenic and control specialists, quality and reliability engineers, and project managers who can run structured development programmes.

It is also the stage where apprenticeships, technician pathways and mid-career upskilling have the highest return, because scaling depends on people who can operate and improve facilities, build repeatable processes and maintain production discipline.

As systems approach scaling (TRL 7–9), two factors dominate whether adoption accelerates or stalls. First is standardisation and benchmarking. Without comparable performance claims, procurement slows and the market fragments into one-off demonstrations. That requires a specific workforce layer: measurement specialists, verification engineers and people who can write test protocols that regulators, primes and infrastructure operators will accept.

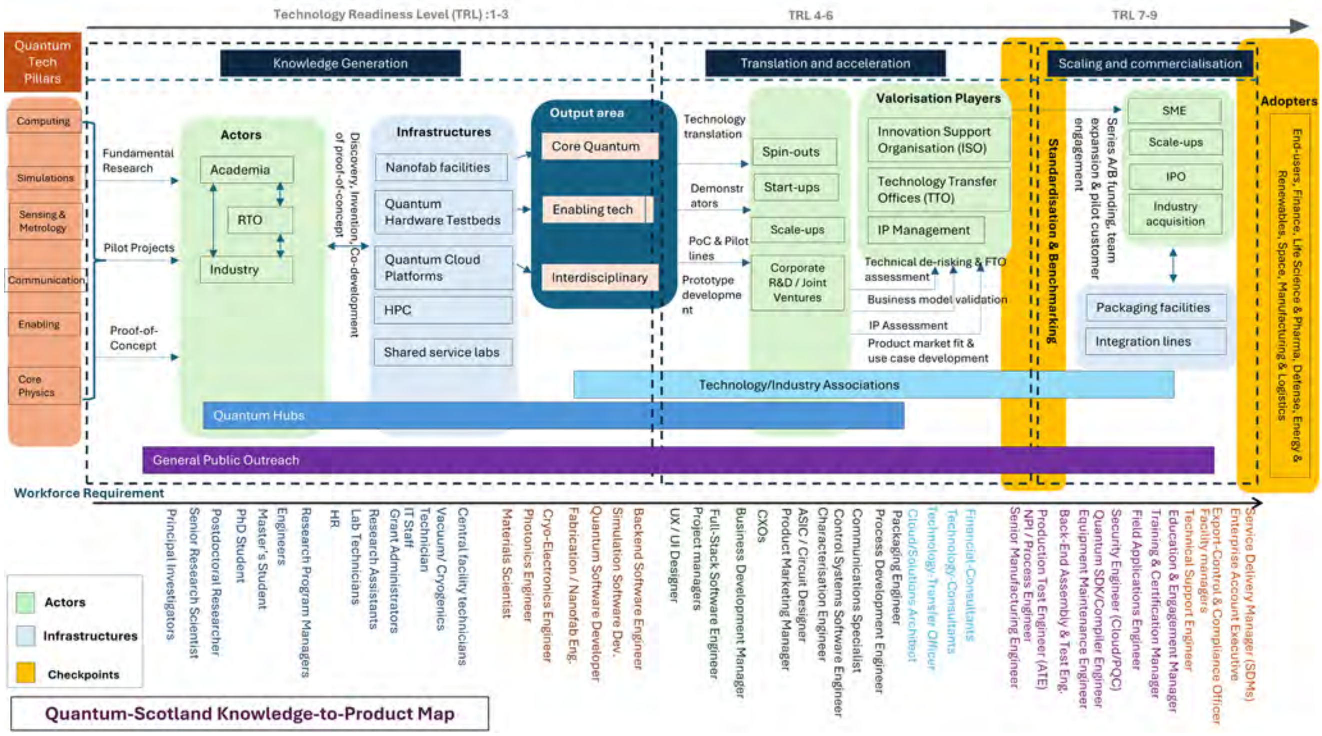


Fig. 4.29 Scotland's quantum knowledge-to-product map across TRLs, linking research, infrastructure, translation, commercialisation and workforce requirements.

Second is packaging and integration capacity, because most adoption happens when quantum capability arrives as a usable subsystem inside a larger product, not as a standalone lab instrument. That shifts demand toward integration engineers, field test teams, technical support, manufacturing engineers and customer-facing application engineers who can translate performance into operational value.

The end users at the top of the chain; energy, defence, finance, life sciences and pharma, space, manufacturing and logistics buy resilience, assurance, speed, sensitivity or security, and they buy it only when it is validated, supportable and serviceable.

What Scotland should keep in mind is that it already has strong foundations at both ends: discovery strength and credible pathways to adoption. The strategic risk sits in the middle, and it is primarily a workforce risk. If Scotland underinvests in the conversion layer - engineering talent, reproducible test and benchmark methods, packaging and integration routes, and the organisations that de-risk translation—then value will leak elsewhere even if the underlying science remains Scottish.

The workforce response is therefore to build continuity across the chain: protect the doctoral base that generates platform breakthroughs, scale Masters and conversion routes that produce systems builders, and expand technician and apprenticeship pipelines that keep facilities and integration capacity operating at industrial pace.

The policy goal is to make the conversion chain continuous, so Scotland can move from ideas to deployable systems without losing momentum, capability or talent offshore.

4.6
Upskilling and adoption

Alongside Scotland's university-led MSc and CDT pipeline, QURECA provides a private-sector workforce and adoption capability that can accelerate near-term delivery. As an early mover in quantum workforce development, it combines CPD-certified training, recruitment and resourcing support, and quantum-readiness consulting that helps adopters move from curiosity to practical roadmaps.

Its offer is designed for mixed backgrounds, upskilling professionals from engineering, software, finance, security and operations into quantum-adjacent roles rather than only training future specialists.

At the front end of the pipeline, QURECA's hands-on learning resources translate complex ideas into accessible toolkits for schools, undergraduates and the general public, widening early exposure and building the awareness layer that feeds future uptake. It also strengthens the next-generation workforce by embedding entrepreneurial thinking through practical exposure to use cases, career pathways and the commercial context in which quantum products are built and adopted.

For Scotland, this kind of private educational and upskilling player is a force-multiplier: it widens entry routes, accelerates conversion of existing professionals into deployable roles, and helps create a workforce that can both build quantum capability and turn it into scalable businesses.

A practical enabler in this workforce chain is QURECA's recruitment and resourcing function, which helps quantum employers and adopters hire faster and more accurately by translating need into clear role definitions, competency frameworks and shortlists across hardware, software and applications.

This reduces one of the most common scale-up frictions: companies know what they want to build but struggle to find people who can operate across the quantum and engineering boundary.

As a member of the Skills Task Force and lead of the WG Skills at UK Quantum, QURECA can also feed real-time market intelligence back into Scotland's training priorities, coordinate employer-led upskilling, and help align university pipelines, short-course provision and conversion routes with the roles that are actually being hired.

Fig. 4.30: QURECA team members at the UK's National Quantum Technologies Showcase (Image: QURECA).

In practice, this strengthens the Scottish ecosystem by tightening the loop between training supply and industry demand, and by accelerating how quickly talent can move into deployable roles.

Practical workforce response Scotland can execute now

1. Protect the doctoral base (CDTs + project PhDs) because it anchors platform IP, lab leadership and future founders.

2. Scale MSc throughput in quantum technologies, photonics and quantum informatics because it produces integration talent quickly.

3. Build the enabling workforce deliberately via apprenticeships and modular upskilling tied to facilities and employers (cleanroom operations, lasers, vacuum, device test, packaging, software engineering for scientific workflows).

This combination avoids a false choice. It keeps Scotland strong at the frontier, while growing the applied skills base that determines whether the sector can absorb investment and scale to higher TRLs.

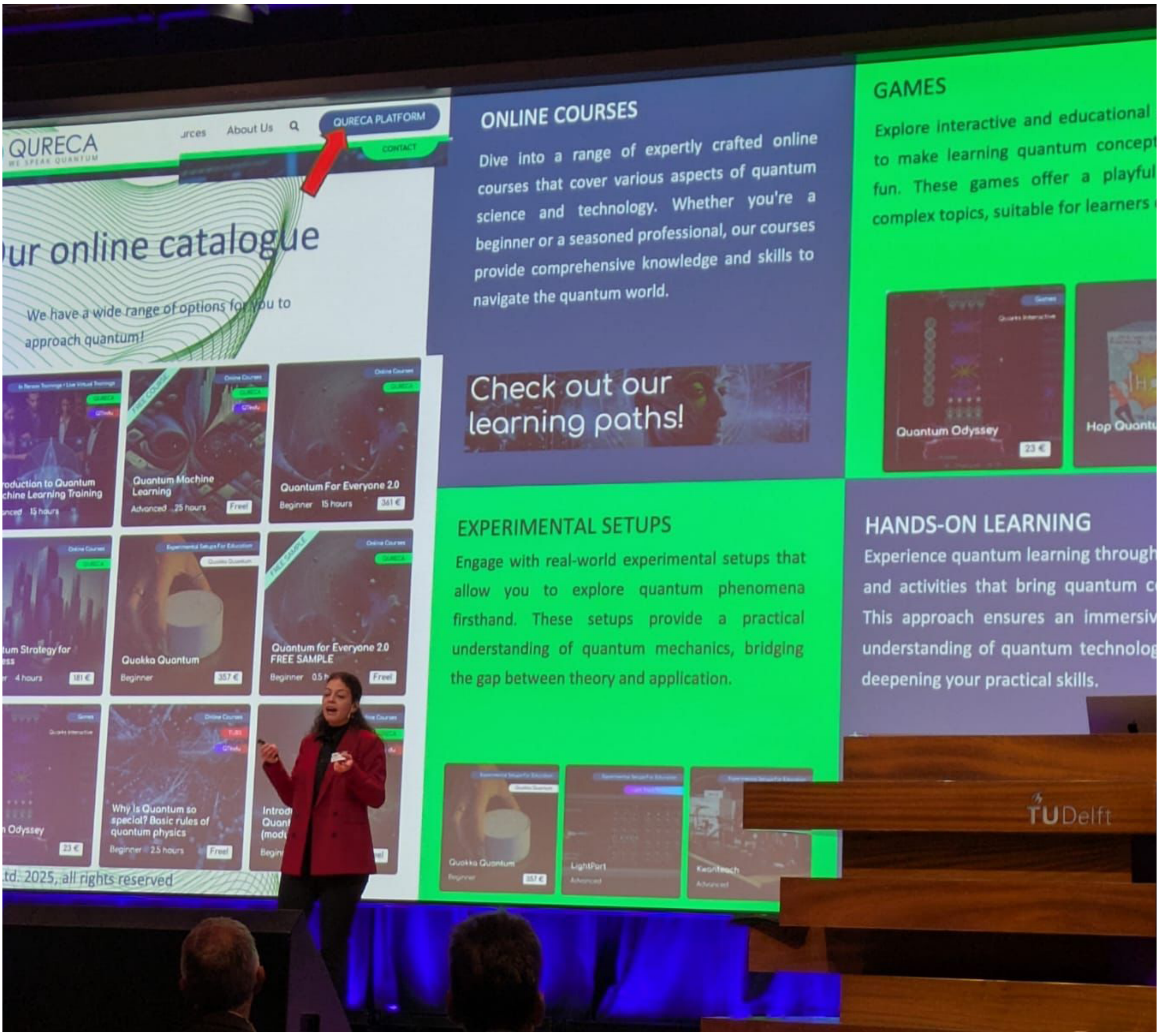


Fig. 4.31: QURECA founder Dr. Araceli Venegas-Gomez (Image: QURECA).

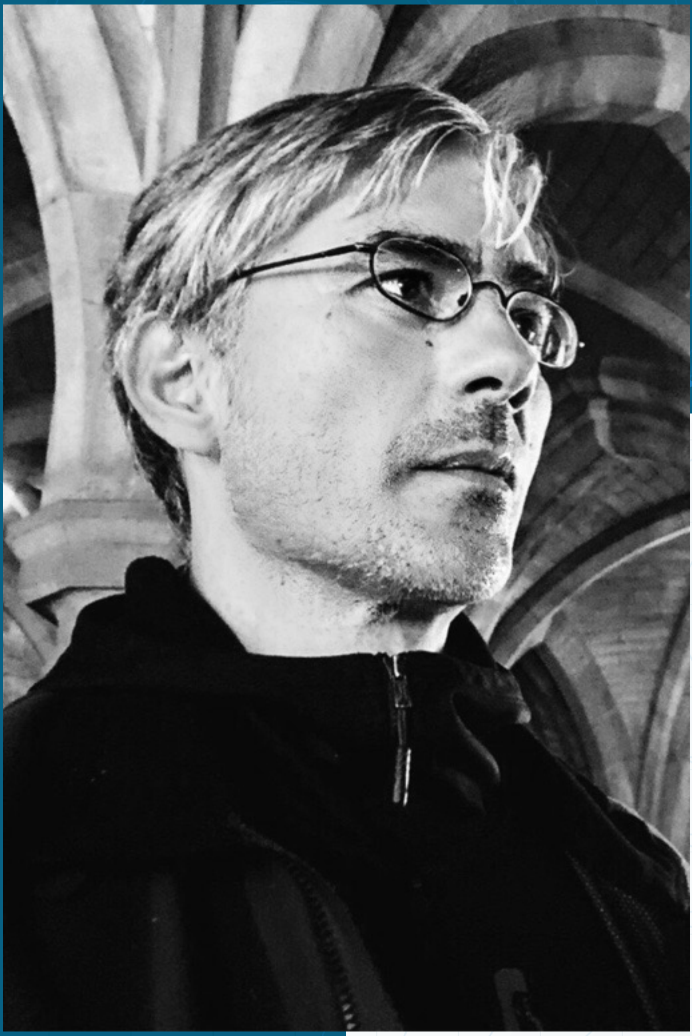
Professor Martin Weides

Professor of Quantum Technologies,
University of Glasgow
Director, James Watt Nanofabrication Centre
Co-founder, Quantcore and Kelvin Quantum

A coordinated investment in cryogenic and photonic integration will be essential — enabling quantum chip testing, cryo-electronics, and quantum interconnects that will underpin the quantum internet and align directly with the UK's national quantum goals.

Glasgow's nanofabrication and advanced manufacturing capabilities already provide a world-class foundation. Expanding these and linking them to a quantum compute and testing platform will enable end-to-end development — from device fabrication to system-level validation at cryogenic temperatures.

By combining nanofabrication, cryogenic testing, and photonic quantum integration, Scotland can deliver a complete innovation pipeline that strengthens the manufacturing of critical quantum technologies and also supports the development of energy-efficient AI hardware. This will reinforce Scotland's role within the UK's quantum landscape and accelerate its vibrant start-up ecosystem — positioning the region to capture a significant share of the global quantum market and drive long-term economic development and industrial leadership.



Professor Antonio Badolato
Chair of Photonic Quantum Technologies/
Royal Society Wolfson Fellow,
University of Glasgow

Scotland already possesses the foundational elements required to establish itself as a critical enabler of quantum technologies, underpinned by world-class semiconductor research, advanced fabrication capabilities, and a robust electronics and photonics ecosystem. We now have a distinct opportunity to look beyond foundational science and focus on translating academic breakthroughs into manufacturable, high-value components and subsystems essential to the quantum supply chain.

Central to this transition are advanced semiconductor materials and chip-integrated platforms. Wide-bandgap semiconductors, such as silicon carbide, alongside nonlinear optical materials and integrated silicon photonics, represent the vanguard of next-generation quantum devices.

Realizing this potential demands streamlined pathways from research-grade fabrication to industrial-scale device development. This requires expanded access to specialized, shared infrastructure and deeper cross-disciplinary integration bridging material science, physics, engineering, and systems assembly. Translational initiatives, such as the Photonics and Quantum Accelerator, are vital mechanisms for bridging the gap between frontier laboratory research and deployable market technologies. By sustaining investment in translational infrastructure, diverse material platforms, and industry-facing partnerships, Scotland could be uniquely positioned to secure a defining role within both the UK quantum ecosystem and the global export market for advanced quantum hardware.

Dr. Lewis Hill
Chair, Future Photonics Leaders (FPL)

The Future Photonics Leaders (FPL) group, a sub-group of the Photonics Leadership Group (PLG), represents early- and early-mid-career professionals shaping the UK's photonics future — the foundation upon which much of today's quantum technology is built. Scotland exemplifies how strong photonics capabilities can accelerate quantum advancement, uniting world-class research, innovative industry, and effective collaboration across sectors.

As part of the PLG, the FPL supports the national ambition to position the UK as a global top-tier leader in photonics innovation, manufacturing, and impact. While the PLG provides strategic coordination between government, industry, and academia, the FPL focuses on empowering the next generation — connecting emerging professionals, amplifying their perspectives, and ensuring that early-career voices actively contribute to shaping the UK's technological and industrial future.

Many of the group's members are graduates of the Scottish University Physics Alliance (SUPA) and maintain strong links with Scotland's thriving photonics and quantum communities. Through collaboration with Photonics Scotland, the FPL continues to promote skills development, cross-sector engagement, and national visibility for photonics as the essential enabler of the quantum economy.

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June 2026

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