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NITI Aayog

NITI Frontier Tech Hub

Transforming India into a leading Quantum-Powered Economy

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Foreword

As the world enters an era where computing power, communication security, sensing precision, and material innovations are being fundamentally redefined, countries that move swiftly will set the terms of global competitiveness.

For India, the stakes could not be higher. Our aspiration to become a developed nation by 2047 will depend critically on our ability to harness deep technologies that multiply productivity, secure our sovereignty, and open new horizons of opportunity for our citizens. Quantum is one such transformative force. It holds the potential to revolutionize healthcare through precision medicine, redefine logistics and energy optimization, accelerate breakthroughs in new materials, and ensure our defence and national security remain resilient in an uncertain geopolitical environment.

The launch of the **National Quantum Mission** in 2023 was an important step in the right direction. The Mission has already made commendable progress in nurturing the ecosystem and building domestic capabilities. But the road ahead requires us to move with far greater scale, speed, and ambition if we are to fully seize the opportunity.

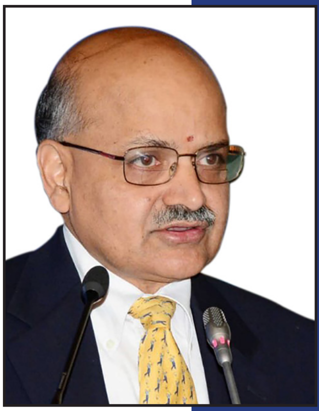
NITI Frontier Tech Hub's roadmap on **Transforming India into a Leading Quantum-Powered Economy**, sets out a comprehensive pathway to realize this vision by 2035. It rightly emphasizes not just the opportunity, but also the risks of inaction. If we do not invest now, India risks being a passive consumer of quantum technologies developed elsewhere, rather than an active shaper of global standards and supply chains.

I am confident that with our unmatched software and engineering talent, our growing scientific base and strong initiatives such as the National Quantum Mission, India can emerge among the world's top three quantum economies.

This roadmap provides a comprehensive blueprint for policymakers, industry, academia, and innovators to move boldly-together-toward a quantum-powered future. Let this be a call to sustained investment, accelerated collaboration, and strategic risk-taking. The window for global leadership is open. Let us ensure India claims its rightful place at the forefront of the quantum revolution.

Dr. V. K Saraswat
Member, NITI Aayog

Foreword



Quantum technologies stand at the threshold of becoming one of the most transformative forces of our time. Their impact will cut across sectors, redefining healthcare, finance, logistics, materials, energy and national security. The nations that act decisively today will not only command the next generation of computing, communication, and sensing capabilities, but will also shape the very architecture of global innovation and trust.

For India, the promise of quantum goes far beyond technology. It represents the opportunity to redefine our place in the world — to lead in a frontier domain from the outset, rather than catching up after others have set the rules. Quantum is not just another sector of innovation; it is the foundation upon which the next era of artificial intelligence, biotechnology, advanced materials, and secure digital infrastructure will be built.

India has taken an important first step through the National Quantum Mission, which has laid a strong foundation for the bigger leap that today's scale of global competition demands. Around the world, leading economies are investing tens of billions of dollars, forging deep public–private alliances, and building integrated quantum value chains that will define who owns the future of computing and secure communication. If India aspires to be among the top three quantum economies by 2035, we must now expand our ambition, accelerate investment, and build capabilities at a pace that matches our potential.

The coming five years will decide whether India becomes a global supplier of quantum technologies — or a consumer dependent on others. We must combine our unmatched talent base, engineering depth, and digital public infrastructure to build a quantum-powered India: one that is trusted globally, competitive economically, and secure strategically.

NITI Aayog's Frontier Tech Hub's roadmap, Transforming India into a Leading Quantum-Powered Economy, outlines this vision. It defines the imperatives and actionable pathways for realizing it, providing a comprehensive assessment of where we stand, where we must go, and what actions are needed to get there. Most importantly, it calls for collective ownership — from policymakers and researchers to entrepreneurs and investors.

The Quantum race is already underway. India has the scientific strength, the entrepreneurial spirit, and the national resolve to win it — but only if we act together, and act now.

B.V.R. Subrahmanyam
Chief Executive Officer
NITI Aayog

Foreword

India's aspiration to become a global leader in quantum technologies must rest not only on self-sufficiency, but on **strategic competitiveness, exportability, and global trust**. The next decade will decide which nations shape the architecture of this frontier — from computing and communication to cryptography and materials.

While hardware and components hold value today, the future belongs to **application software and services** — a space that plays directly to India's strengths in digital innovation. Our goal is clear: by 2035, India must be among the **top three quantum economies**, influencing not just adoption but the very direction of the global quantum landscape.

The Roadmap to Transform India into a leading Quantum-Powered Economy by NITI Frontier Tech Hub lays out how. It envisions India as a **net exporter of quantum solutions** — from full-stack software platforms and cryptographic libraries to quantum algorithms for finance, logistics, and healthcare. It positions India as a **trusted quantum partner for the Global South**, providing secure, ethical, and affordable technologies that solve shared development challenges. It calls for leadership in **quantum diplomacy**, advancing global standards and market access through partnerships with the Quad, EU, ASEAN, and beyond.

India must also build **world-class R&D and manufacturing hubs**, foster an **India-led Global Quantum Benchmarking Consortium**, and become one of the **top three global destinations for quantum and allied talent** through a culture of high "Ease of Doing Science" and seamless innovation-to-market translation.

The National Quantum Mission provides a strong foundation to leapfrog from. If we act with the ambition and speed this moment demands India can shape the global quantum era, not just participate in it.

The cost of inaction is one we cannot afford: dependence on others for the technologies that will determine our economic strength, strategic autonomy, and global influence in the years ahead.

I am deeply grateful to the Expert Council for their invaluable guidance and insight in shaping this roadmap, and to Amit Singhee and the team at IBM for their exceptional partnership and thought leadership.

Debjani Ghosh
Distinguished Fellow, NITI Aayog
Chief Architect, NITI Frontier Tech Hub

Executive Summary

Quantum technologies are poised to become one of the most disruptive technology verticals of the century. Imagine a future where a child in a remote village in Rajasthan is diagnosed with a rare genetic disorder. While diagnosis through genomic sequencing is becoming increasingly feasible, designing personalised treatments remains complex and time-consuming. By 2035, India's homegrown quantum computing platforms may help accelerate drug discovery by simulating molecular interactions between disease-relevant proteins, coded by the child's genome, and thousands of therapeutic candidates. Instead of relying solely on expensive wet-lab screening, researchers could use quantum-enhanced algorithms to identify promising molecules, simulate their properties, and predict their efficacy, substantially reducing early-phase discovery timelines. Although clinical validation will still require years, these advances could pave the way for faster, more accessible precision medicine, even in rural healthcare settings. The medicine would be delivered via India's health digital public infrastructure (DPI) and monitored using quantum-enhanced diagnostic sensors. The child receives life-saving treatment not in a top-tier urban hospital, but in a digitally connected primary health center nearby.

This is the kind of leap quantum technologies promise across healthcare, materials, climate science, finance, and more. The predictive power of quantum computers will not only accelerate innovation but also democratize it as the hardware matures and becomes widely available — making precision healthcare, advanced materials, and secure digital infrastructure accessible to all. They will become the primary technology differentiator for nations and economies, with transformative impact across a vast range of applications. By 2035, they could unlock USD 1–2 trillion in new value across industries such as finance, energy and materials, logistics, pharmaceuticals, and medical/healthcare products.[1]

Quantum technologies leverage the principles of quantum physics for breakthrough capabilities that go beyond classical systems. This includes four major vectors:

1. **Quantum computing,** which uses quantum bits or qubits and quantum information, promises computation that is exponentially faster than classical computing for certain problems such as simulating nature, optimization, machine learning and factoring large numbers. At the same time, it could also be able to break RSA cryptography codes rendering much of the data and communications in today's world vulnerable. Quantum advantage[2] over classical computing is expected to be achieved in specific domains within this decade.

2. **Quantum communication,** which uses quantum key distribution and entanglement, enables ultra secure communication, that cannot be intercepted without detection. As quantum computing threatens to break existing cryptographic systems, quantum communication networks will become essential for safeguarding military, government, and critical infrastructure communications against even the most advanced adversaries. Quantum key distribution (QKD) has already demonstrated in long-distance scenarios in multiple countries, including India, China and the US.

[1] McKinsey and Company, Quantum Technology Monitor, Jun 2025.
[2] Refer Sec 2.2.1 for details.

3. **Quantum sensing and metrology**, which uses quantum mechanical effects for highly sensitive measurements, e.g. atomic clocks and magnetometers. Such sensitive instrumentation will be critical for space, defence and aerospace applications, among others. Applications of quantum sensing are in active development and look plausible for strategic applications by 2035.

4. **Quantum materials**, which leverage quantum mechanical properties for novel materials and devices, that power and enable the other three vectors.

Globally, quantum remains at an early but rapidly advancing stage—fuelling a new international technology race. Governments and industry leaders in the US, China, Europe, and Asia have dramatically ramped up investments, with public funding alone surging past USD 10 billion annually in recent years. At stake is not just economic value, but national security, digital sovereignty, and future industrial competitiveness.

Recognizing the magnitude of this opportunity and risk, India launched the National Quantum Mission (NQM) in April 2023, allocating INR 6,003.65 crore (about USD 730 million) through 2030–31 to "seed, nurture, and scale up" domestic quantum R&D and position India as a leader in the global quantum ecosystem. While this is a critical first step, global momentum and the scale of the opportunity demand far greater ambition and urgency.

An ambitious but achievable vision for India's Quantum Economy in 2035, would be:

- Incubating at least 10 globally competitive quantum startups, each surpassing USD 100 million in revenue,
- Capturing over 50% of the value in the global quantum software and services market by harnessing our software and engineering strength,
- Achieving meaningful, scaled deployment of quantum technologies—home-grown and global—in strategic sectors[3] across India,
- Commanding critical positions in the global quantum supply chain for both hardware and software, creating strategic dependencies and value, and
- Becoming a source of foundational scientific breakthroughs, with world-class research and intellectual property creation in quantum science and engineering.

To realize this vision, India must rapidly bridge current gaps through coordinated national action. Key priorities would include:

1. **Expand the Quantum Workforce:** Grow the scientific, deep engineering and professional workforce that is deployment-ready by an order of magnitude in 2-3 years.

2. **Catalyse Industry Engagement and Investment:** Significantly increase the awareness among industry leaders and in government sectors of the potential of quantum technology for their sector and stimulate much higher investment into quantum technologies in 2-5 years.

[3] "strategic sector" in this report refers to defence, intelligence and entities dealing with national security.

3. **Accelerate Lab-to-Market Transition:** Significantly improve ease of doing research, of technology validation and of taking technology from lab-to-market, within 2 years.

4. **Grow Fundamental Science and Risk Appetite:** Take steps to substantially grow quality and quantity of fundamental scientific research, while also growing risk appetite in our funding entities and research institutions in 2-5 years.

5. Make Indian domicile attractive for Indian startups so that >90% deep tech Indian startups choose to stay domiciled in India.

6. **Lead in Global Standard Setting:** Engage actively with global standards bodies and take leadership in international standard setting related to quantum technologies to ensure that Indian products have access to global markets.

7. **Strengthen trade:** Ensure strong trade relations and ease of technology export and import, especially in quantum related technology areas.

Quantum technologies are still in their formative stages globally, offering India a rare opportunity to shape the trajectory of a foundational technology—unlike previous technological waves where India often had to play catch-up. This time, India can position itself as a global leader from the outset. Realizing this potential, however, will require bold, coordinated, and immediate action: accelerating scientific research, fostering rapid technology development, scaling up workforce preparation, and enabling commercialization at pace and scale.

The remainder of this roadmap details a comprehensive vision for India's quantum future by 2035. It identifies India's unique strengths and critical gaps, sets forth actionable recommendations, and highlights the risks of inaction at this pivotal moment.

The roadmap is the first version of this perspective. The insights and recommendations in this roadmap will be periodically reviewed to reflect the evolution of technology as well as the global contest. This will keep India's strategy for Quantum Technologies relevant, resilient and future ready.

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1. VISION FOR 2035 AND BEYOND

By 2035, the global quantum economy will be defined, with clear front runners and well-established ecosystems. For India to make a lasting impact and secure a strategic advantage, it must act decisively over the next decade through coordinated investments, accelerated intellectual property creation, and bold partnerships spanning academia, industry, and government. This section outlines the key elements of this Vision in terms of measurable targets and milestones that we must achieve by 2035. These targets are ambitious and achieving them will need India to break through key barriers and fast-track progress across multiple fronts. The rest of the roadmap details those barriers—and lays out concrete recommendations to overcome them and achieve these unlocks and needed acceleration.

1.1 Envisioning a Quantum-Powered India

1.1.1 10+ Quantum Champion Startups with Global Leadership with USD 100M+ Cumulative Revenue (V1)

India should aim to incubate and scale at least 10 globally competitive quantum startups, each surpassing USD 100M in cumulative revenue by 2035. While quantum sensing and communications are currently more mature, India has the potential to drive deep growth across all four quantum verticals. Breakthroughs in quantum software—leveraging India's strengths in information technology (IT) services and algorithmic innovation—are expected to lead this wave, supported by robust public and private investment.

1.1.2 India Captures Over 50% of the Global Quantum Software and Services Market Value (V2)

Building on its global dominance in IT services and strong skills in high-performance computing and natural sciences, India is uniquely positioned to lead in quantum software and services. With major Indian IT firms already investing in quantum skilling and research, India can exceed 50% global market share in quantum software, including algorithm development, middleware, cloud-based quantum platforms, and tools for hybrid quantum-classical workflows.

1.1.3 Quantum Technology Deployed across at least 3 Major Sectors, including Strategic Domains (V3)

By 2035, quantum technologies should be deployed at scale in sectors such as defence (quantum sensing, secure communications), chemicals, petroleum and mining (quantum simulations, sensing), healthcare (quantum algorithms for drug discovery, diagnostics), and finance (quantum optimization and cryptography). Strategic adoption by public sector entities and integration into mission-critical systems should be a national priority.

1.1.4 India Achieves Quantum Atmanirbharta and Controls Critical Points in Global Supply Chains (V4)

India should aim to be a net exporter of both core and peripheral quantum hardware and software technologies. This includes contributions to superconducting and photonic platforms, quantum processors, dilution refrigeration components, control systems, and post-quantum cryptography libraries. India must also play a key role in standards development to ensure its technologies are globally interoperable.

1.1.5 India Emerges as a Hub for Foundational Scientific Breakthroughs in Quantum Technologies (V5)

With growing investment from the National Quantum Mission and global collaborations, India should produce scientific research at par with top global institutions. By 2035, Indian researchers should regularly publish in high-impact journals (e.g., *Nature*, *Science*, *PRL*) and contribute fundamentally to the understanding and advancement of quantum science and engineering.

1.2 Key Milestones for a Quantum Economy

It is important for India to establish granular milestones over the next 10 years and stay on track to achieve the ambitious, but critical, vision set in the previous section. A set of such milestones are laid out below in two phases: 2025-2030 and 2030-2035. These milestones will create the foundation for achieving the Vision for 2035.

Phase 1: 2025–2030 | Building Scale and Market Momentum

- Deliver on National Quantum Mission Milestones as per plan
  - » Complete establishment of quantum technology hubs and testbeds.
  - » Operationalize mission-mode projects across four verticals (Computing, Sensing, Communications, Materials).
  - » Fund and incubate 50+ startups and research projects with commercialisation potential.
  - » At least 5 startups reach global markets and establish globally leading revenue streams.
- Develop peripherals manufacturing of global standards by Indian private sector.
  - » Reduce dependency on import for basic components like BNC cable, wires, optics and optomechanics along with some custom chips.
- Accelerate Industry Adoption of Quantum Technologies
  - » Demonstrate quantum advantage in India for useful applications when compared to classical algorithms, even before fault tolerant quantum computing becomes real.
  - » Launch 25+ industry-focused quantum pilot projects across sectors such as banking, pharma, energy, chemicals, logistics, and manufacturing.
  - » Incentivize co-development programs between startups and large enterprises to validate quantum solutions.
  - » Establish 3–5 sectoral sandboxes to demonstrate quantum advantage in practical applications.
- Seed and Scale the Indian Quantum Software Industry
  - » Create a national accelerator for quantum software startups.
  - » Enable commercial licensing of algorithms and SaaS quantum tools for domestic and global markets.
  - » Train 100,000+ developers through national skilling programs in software stacks such as Qiskit, Cirq, and Indian-developed stacks.
- Enable Strategic Sector Adoption of Quantum Technologies
  - » Deploy quantum sensors, encryption-based communication networks, and quantum algorithms and tools in defence, space, oil and gas, energy and public infrastructure.
  - » Mandate quantum-readiness planning in public sector innovation roadmaps.
    - Conduct technology integration trials in DRDO, ISRO, HAL, Indian Railways, and ONGC.
- Develop and Pilot Quantum Resilient Technologies
  - » Establish regulatory framework and guidelines for the adoption of quantum resilient encryption technologies both for public and private sectors, to drive the migration to quantum resilient data and communication architectures.

- » Launch national testbeds and trials for post-quantum cryptography (PQC).
- » Deploy PQC in government IT systems and critical infrastructure.
- » Co-create global PQC benchmarks and export-grade standards with industry and academia.

Phase 2: 2030–2035 | Achieving Global Competitiveness and Strategic Leadership

- Position India Among the Top 3 Nations in Quantum Readiness
  - » Maintain and grow a top-tier talent pool across academia, startups, and enterprises
  - » Top 3 ranking in top-tier scientific publications.
  - » Enable annual patent filings in quantum to cross 1,000+ across domains.
  - » Lead international quantum standards bodies and consortia.
- Grow a Globally Competitive Quantum Startup Ecosystem
  - » Support 10+ startups to reach USD 100M+ in cumulative revenue.
  - » Anchor quantum unicorns with both product and platform intellectual property (IP) in India.
  - » Establish quantum venture funds and initial public offering (IPO) pipelines.
- Own Strategic Segments of Global Quantum Supply Chain
  - » Achieve dominance in at least 3–4 quantum stack components (e.g., cryo-electronics, photonic qubits, error correction chips, quantum control stacks, PQC stacks).
  - » Export India-made quantum components and subsystems to global platforms.
  - » Build a quantum export corridor with trusted partner countries.
- Achieve Full-Scale Strategic Sector Integration
  - » Set a target date and replace legacy systems with quantum resilient platforms in national security, space, and critical infrastructure.
  - » Use quantum simulations and optimizations to guide national climate, health, and resource policies.
  - » Run high-impact grand challenges to solve persistent national problems using quantum advantage.
- Establish India as a Global Quantum IP and Deployment Hub
  - » Host global conferences, standard bodies, and inter-governmental tech partnerships.
  - » License Indian quantum software and hardware to 30+ countries.
  - » Lead collaborative moonshots on quantum climate models, medicine, and supply chains.

1.3 Global Leadership and Competitiveness

India's aspiration to become a global leader in quantum technologies must be built not only on self-sufficiency, but on strategic competitiveness, exportability, and global trust. While equipment, components and hardware have higher market value currently, in the coming decade, application software and services are expected to have greater value, which plays directly to India's strengths.[4] The next decade is not just about building capabilities at home but about influencing the direction of the global quantum landscape. India must be a top 3 quantum economy.

1.3.1 India as a Net Exporter of Quantum Solutions

By 2035, Indian companies and startups should be exporting full-stack quantum software platforms, embedded cryptographic libraries, and components of scalable hardware to global markets. This includes custom-designed quantum algorithms for sectors like finance, logistics, climate modelling, and healthcare that are deployable worldwide.

1.3.2 Trusted Quantum Partner for the Global South

India must emerge as the trusted provider of secure, ethical, and cost-effective quantum technologies for emerging economies filling the need for affordable, adaptable solutions that address shared challenges such as water security, crop resilience, and disaster forecasting.

1.3.3 Quantum Diplomacy and Market Access

India should lead with quantum diplomacy forming bilateral and multilateral technology partnerships with the Quad, EU, African Union, ASEAN, and other regions to establish interoperable standards, ethical frameworks, and joint innovation programs that ensure Indian quantum products gain seamless global market access. A recent example from the global setting is India's alliance with the CERN-based Open Quantum Initiative of the Geneva Science and Diplomacy Anticipator. Several advanced economies have already implemented export controls on critical quantum technologies and components; India has a unique opportunity to position itself as a champion of equitable access and trusted global trade. By advocating for balanced frameworks that support both security and innovation, India can help shape international norms that enable responsible technology sharing, especially with countries in the Global South.

1.3.4 Home to Global Quantum R&D and Manufacturing Hubs

India must host globally recognized quantum R&D zones and advanced manufacturing facilities, like Amaravati's Quantum Valley and other emerging tech clusters and create new ones across the country. These should offer open infrastructure to international partners while safeguarding national interests.

1.3.5 India-led Global Quantum Benchmarking Consortium

Establish an India-anchored international consortium for benchmarking quantum performance and reliability developing fair, transparent, and globally recognized metrics for quantum processors, cryptography, and algorithms.

1.3.6 India in top 3 preferred destinations for top global quantum and allied talent

Establish high Ease of Doing Science, enable competitive remuneration for quantum related careers, and strong translation mechanisms with quantum innovations being applied in industry, to engage and attract strong global talent to India. This should cover not just talent in the quantum technologies domain but also in allied areas such as electronics, hardware engineering, optics, microwave, etc. that are required for integrated R&D of quantum technologies.

[4] McKinsey and Company, Quantum Technology Monitor, Jun 2025.

2. STATE OF QUANTUM TECHNOLOGY IN 2035

2.1 Overview of quantum technologies, their evolution and adoption in the economy

It was 1925 when key scientific discoveries led to the genesis of modern quantum mechanics – the theory that describes behaviour of matter and matter-energy interaction at atomic scale. United Nations has proclaimed 2025, the 100th year of modern quantum mechanics, as the International Year of Quantum Science and Technology[5] to celebrate the impact of quantum science driven technological progress of the last century, and the impact it has had on the world. That wave of scientific revolution led to significant technological developments including:

(i) Quantum photonics that revolutionized medical imaging and diagnostics,

(ii) Quantum chemistry that led to development of new vaccines and drugs,

(iii) Quantum mechanics that was at the root of semiconductors that underpin modern economy,

(iv) Quantum physics that lead to invention of LASERs, LEDs and the like, and

(v) Quantum mechanics that underpins modern GPS systems.

While the progress has been truly fundamental and pathbreaking over the last century, the technologies developed have merely used deeper *understanding* of matter and its interactions in developing the new technologies. We are at the cusp of a second wave of developments where technologies will *use quantum phenomena* – like superposition, entanglement, Heisenberg's uncertainty principle, no cloning theorem and tunneling – in both development and use of these technologies. This second wave is expected to have a similar revolutionary impact as the first one, as this is going to be built on top of phenomena that are fundamentally different from any other used so far. These modern quantum technologies are broadly classified into 4 categories:

(i) Quantum computing – use quantum phenomena to perform calculations better, faster or more cost and/or energy efficiently,

(ii) Quantum communication – use quantum phenomena for secure communications,

(iii) Quantum sensing – use quantum phenomena to have deeper understanding of the world, and apply it to varied applications, and

(iv) Quantum materials – study material properties using quantum principles and help develop novel ones.

2.2 Quantum Sub-Sectors

2.2.1 Quantum Computing

Quantum advantage would have happened. Quantum advantage is said to be achieved when:

"[..] information processing task on quantum hardware that satisfies two criteria: (i) the correctness of the output can be rigourously *validated*, and (ii) it is performed with a *quantum separation* that demonstrably offers superior efficiency, cost-effectiveness, or accuracy than what is attainable with classical computation alone."[6]

[5] https://quantum2025.org
[6] O.Lanes et. al., "A framework for quantum advantage", arXiv:2506.20658.

It is to be noted that the above calculations could include classical computing as well. In other words, we are comparing classical + quantum compute vis-à-vis classical compute alone; it is the presence of quantum computing in the mix that demonstrably leads to the above differentiation.

Quantum advantage is expected by 2026-28. This is likely to be in abstract realm at first expanding into business use-cases in due course. It is expected that quantum value unlock will happen in this timeframe as well. This requires significant improvement in maturity of both quantum hardware and software towards general availability.

Quantum computing scaled to 100K quantum bits (qubits) regime. There are many quantum hardware roadmaps being announced by different players in the market such as IBM, Google and others. We can infer from them that the next decade will see qubits to scale to 100K regime with quantum processing units (QPUs) becoming part of hyperscalar deployments.

Early quantum fault tolerance deployed. Many hardware original equipment manufacturers (OEMs) have indicated that error correction is likely to be achieved before 2030. This means that by 2035 error correction will be deployed and scaling of logical qubits will be underway. It is likely that there will be systems with over 200 logical qubits available for use.

Era of quantum-centric computing underway. Novel algorithms emerging in quantum computing indicate that quantum and high-performance computing (HPC) will have close inter-play in unlocking quantum value. Quantum-HPC interplay works at two levels: (i) quantum algorithms requiring HPC capability for its performance, and (ii) abstract quantum algorithms at workflow level that needs to optimize the use of resources based on cost/performance/quality and tradeoffs therein.

2.2.2 Quantum Materials

Development of efficient single-photon sources and detectors, and entangled photon sources. The efficiency of single-photon sources and detectors is likely to see significant improvement in the coming decade. The quality of entangled photon sources is expected to significantly increase as well.

Materials for solid-state quantum computing and quantum metrology. High-quality two-dimensional materials are the platform for the realization of some of the most promising quantum bit and quantum metrology architecture. The main systems which are being globally pursued, while nationally no presence, are high quality semiconducting quantum well heterostructures such as Si/SiGe and GaAs/AlGaAs. Both systems are the platform to realize quantum hall resistance standards, quantum electrical sensing and quantum charge pumping and counting circuits. Figure 1 shows roadmap, from short term to long term, more broadly for materials for quantum landscape.

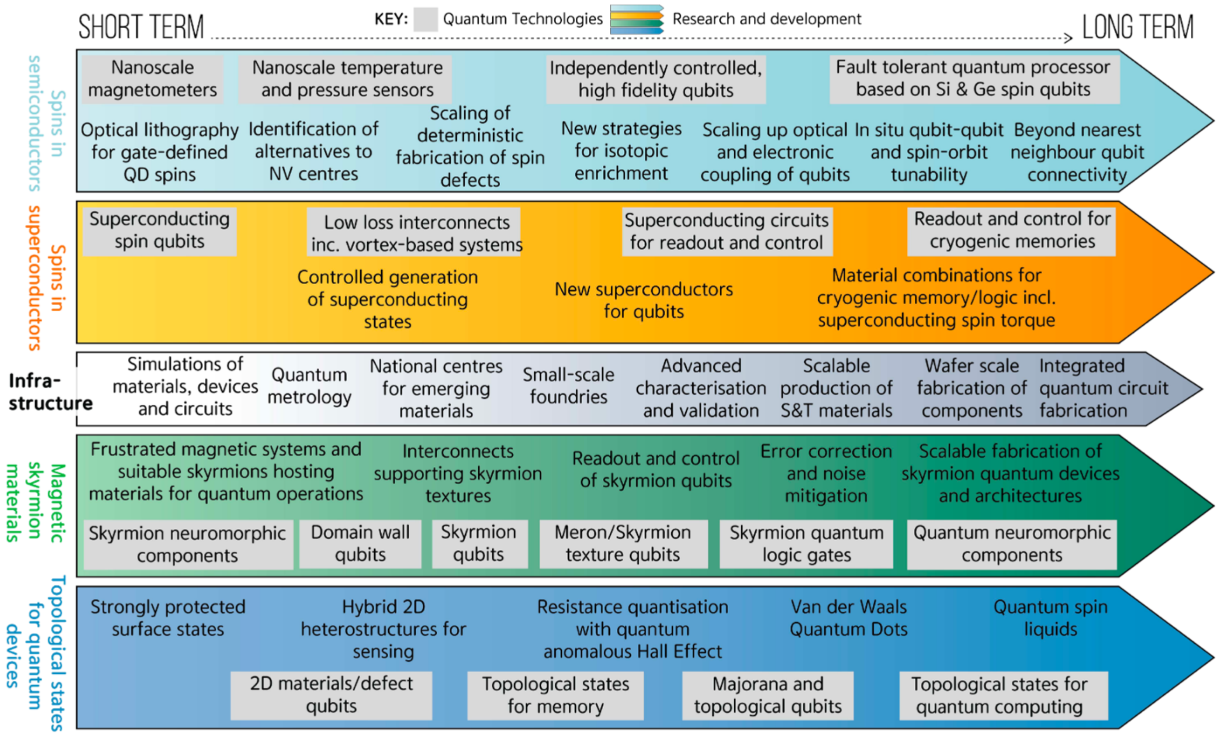

Figure 1: Materials for Quantum - roadmap.[7]

Materials for neuromorphic computing. Quantum materials offer a promising foundation for this innovation. Their exceptional electronic and magnetic characteristics enable the creation of energy-efficient hardware capable of managing vast amounts of information. For instance, materials such as transition metal oxides and 2D van der Waals structures display strong correlations and non-linear responses, which are crucial for mimicking neural processes like adaptive learning and memory (Figure 1). These advancements pave the way for real-time data classification and sophisticated applications in artificial intelligence and machine learning.

Materials for energy harvesting and storage. Quantum materials like perovskite compounds are revolutionizing solar energy by enabling efficient sunlight-to-electricity conversion. In energy storage, materials such as topological insulators and graphene enhance batteries and supercapacitors with faster energy release and greater charge storage, vital for renewable systems. Tin oxide quantum dots promise high stability, cost-effectiveness, and superior energy capacity in solar cells and batteries. Additionally, composites like titanium dioxide quantum dots on graphene improve lithium and sodium storage, offering higher capacity and cycle stability for advanced batteries. These innovations drive sustainable energy solutions, making renewable systems more efficient and scalable.

2.2.3 Quantum Communication

Satellite-based secure quantum communications of over 2000 km. Satellited based quantum communication will be increasingly mainstream with ranges of over 2000 km being available. A lot of trials are expected to be performed over different ranges, including field testing. It is highly likely that it will be deployed in strategic sector.

[7] Banerjee et. Al., "Materials for Quantum Technologies: a Roadmap for Spin and Topology", arXiv:2406.07720.

Inter-city quantum key distribution over 2000 km. Intercity quantum key distribution is likely to expand in scale to over 2000 km. Wider adoption and deployment of this technology is likely starting from key strategic and government sectors, and perhaps in some civilian space as well.

Multi-mode quantum networks with quantum memories towards a global quantum internet. This will be an important development especially quantum memories. This will be an important element in scaling the quantum network and to make it broadly available. Quantum memory technologies would have matured and likely to be deployed to support multi-mode quantum network.

2.2.4 Quantum Sensing

High sensitivity magnetometers in atomic systems for precision timing, communications and navigation. Different magnetometers are undergoing field testing now and will expand in the coming years. More application use-cases are likely to emerge in the next decade. It is likely that these technologies will be deployed and would have made inroads, especially into strategic sectors.

Quantum imagers. This field will see many proof-of-concepts (PoCs) being developed in the next 5 years. It will then undergo field testing, and some very well-defined use-cases may see deployment as well.

Gravimeters. These are already in use in many sectors like mineral or oil detection. These technologies will be made more portable, making it easy to use. This change is likely to unlock many more applications.

Atomic clock. Atomic clocks are seeing significant transformations and are moving towards optical frequency technology from microwave one.[8] This greatly enhances precision and stability. Continued miniaturisation and integration with advanced electronics is set to continue through the coming decade. This will lead to applications like networked battlefield capabilities, global navigation satellite system resilience, 6G networks, satellite navigation, deep space exploration amongst others.

Inertial navigation. This sector has significant strategic importance and attention being paid to the development this technology. A lot of progress is expected towards deployment of this technology starting in strategic sector and then to other possible applications in civilian space.

2.2.5 **Convergence with other cutting-edge technologies**

Quantum computing and High-Performance Computing (HPC). Novel quantum algorithms leverage the power of HPC especially in applications using quantum simulations. This interplay is likely to continue both at algorithmic as well as workflow levels.

Quantum computing and Artificial Intelligence (AI). AI is making its presence felt in two ways: (i) AI being used to implement quantum better; examples of which is efficient transpilation such that the circuit depth and the use of 2-qubit gates is reduced, and (ii) quantum machine learning targeting AI problems like classification, prediction, anomaly detection amongst others, which can make AI systems even more capable of discerning complex patterns in data.

[8] https://www.futuremarketinsights.com/reports/atomic-clock-market

Quantum sensing and computing in applications. As higher quality sensors and nanobots are deployed in applications such as health diagnostics, more sophisticated dataset will emerge requiring novel quantum algorithms to unearth patterns in the dataset. Thus, a new class of solutions are likely to emerge wherein quantum sensors are used at a lower level to generate data at a finer resolution, and quantum algorithms being used at application level to reveal insights.

Quantum communications and computing. This is perhaps further out in the horizon where in different quantum computing modalities need to be connected and/or need to connect logical quantum computers in different hyperscalar centers that are geographically separated. This will be the emergence of quantum computing network.

Quantum materials and computing. New materials are being explored as candidate for topological quantum computing, photonic quantum computing using semiconductor materials, novel spin qubits etc. Quantum materials would also be needed to solve the problem of connecting different quantum computing modalities or in the era of quantum internet.

2.3 Quantum Technology Stack and Value Chain

The Quantum Stack: The quantum stack refers to an end-to-end view of quantum technology (Figure 2). There are multiple abstract layers in the stack:

2.3.1 *Quantum hardware:* This is the layer that exhibits quantum properties. At the bottom are the materials; these are used to create quantum devices like qubits, transduces, sensors and entangled sources. Materials and quantum devices together form the hardware layer in the stack.

2.3.2 *Non-quantum hardware and software:* This layer is immediately on top of the quantum hardware and parts in this layer supports quantum properties of quantum hardware. These are in and of itself non-quantum or classical hardware or software.

(i) *En*vironments: cryogenics, compressors, UHV chambers, thermometry – that immediately surround the quantum hardware,

(ii) Components: key components – cryoRF, SNSPDs, cryoLNAs, connectors and wiring, I/O, detector arrays – that are either embedded or connects the elements of the environment,

(iii) Control and correction: this layer – cryoCMOS, SFQ, control electronics, stabilized lasers – controls the quantum hardware including its stability and correctness,

(iv) Software: this is the first software or firmware layer that provides programmability and control of hardware from higher layers, and

(v) Network: this layer includes protocols, specialty cladding fibre that bring in the first physical networking infrastructure.

2.3.3 *Providers:* With the previous layers, an abstraction for quantum hardware is in place. This layer focusses on higher levels of abstraction:

(i) *Quantum products:* this layer defines the products like computing, secure communications and sensing network,

(ii) *Cloud services:* natural progression on top of products level, to position in the context of a cloud so that it is accessible to end-users, and

(iii) *Algorithms:* once the quantum products are available on cloud, then the next aspect of the problem is to consider is to how to use is efficiently and effectively in application context.

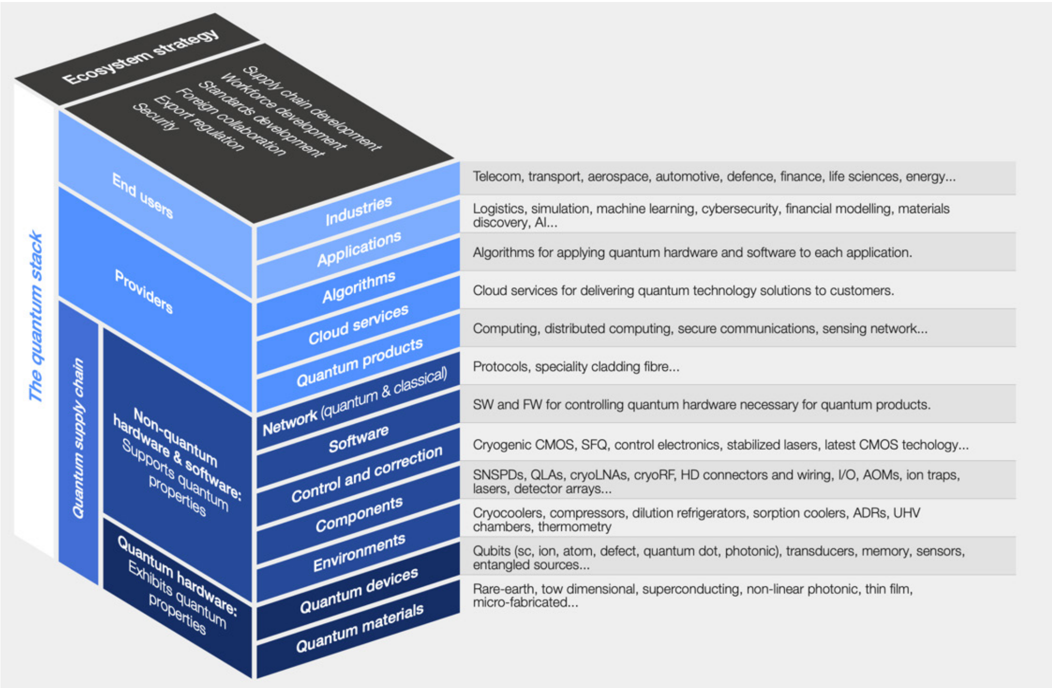

Figure 2: The Quantum Stack.[9]

2.3.4 **End users: This layer refers to ultimate consumers of the quantum technologies.**

(i) *Applications:* with algorithms in place, the next level of abstraction is to explore the use-cases like logistics, cybersecurity and materials discovery, and

(ii) *Industries:* on top of the applications comes the industries – telecom, aerospace, pharmaceuticals, defence, automotive – who will consume the use-cases developed.

The physical infrastructure layers, that include quantum hardware and non-quantum hardware, is cumulatively referred to as quantum supply chain. This distinction is important as the supply chain has geographical dependence while other layers in the stack can technically be managed by policy frameworks focusing on capacity and capability development.

Table 1 maps some of the Indian organizations that are developing capabilities in different layers of the stack. Most of these are startups with different levels of maturity and funding. There are quite a few active startups across the layers, however, many of these are early-stage startups, and there are segments where there are gaps. The only meaningful investment from industry is from the strategic sector, in this case the Indian Navy. The National Quantum Mission provides support across many of these layers, and the Innovation for Defence Excellence (IDeX) scheme, while not specific to quantum technologies, provides some support in the end user and provider layers, where the target industry is the defence sector.

[9] "Quantum Economy Blueprint – Insight Report", World Economic Forum, Jan 2024.

Layer	Segment	Example companies/orgs.
End users	Industries	Indian Navy
	Applications	Accelequant
Providers	Algorithms	Acclequant, QKrishi, BQP
	Cloud services	
	Quantum products	QNu Labs, QPiAI, QuBeats
Non-quantum hardware and software	Network	
	Software	Qulabs
	Control and correction	Qnulabs
	Components	Dimira, Prenishq, QuPrayog
	Environments	
Quantum hardware	Quantum devices	Quanastra, DeepLase, QpiAI
	Quantum materials	Pristine Diamonds, Quan2D

IDeX

National Quantum Mission

Table 1: Indian quantum stack and representative organizations (not exhaustive) in each layer and overlay of supporting national initiatives.

The Quantum Value Chain. It is vital to understand the overall supply chain for the quantum ecosystem as it provides a framework to understand the strengths and weakness. Figure 3 shows various stakeholders in the quantum ecosystem and their interrelations. The top and bottom portion are academic and regulatory ecosystem while the middle box is the actual supply-chain. Top part has stakeholders whose role is to provide new insight, scientific inquiry and education; it also has component that interfaces the academic ecosystem with industrial sector. Bottom portion interfaces industry with funding, collaboration opportunities within the industry and government ecosystem as well as provide regulatory environment covering commercial and IP management. The arrows in the value chain indicates sequencing or dependency.

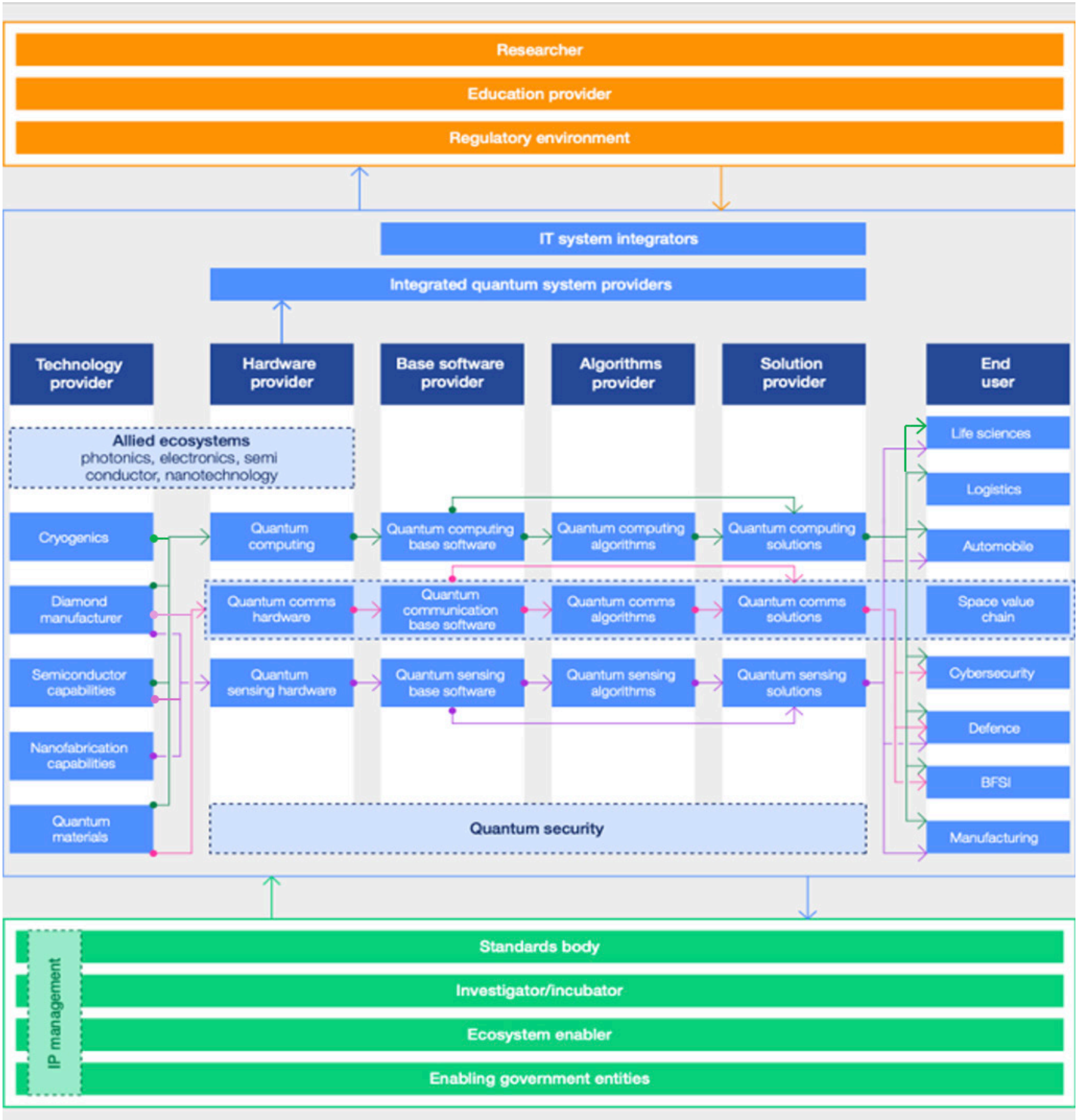

Figure 3: The Quantum Value Chain.[10]

The supply chain portion (middle box) of the value chain is the actual aspects of technology development. It is to be read from left to right wherein materials are the primary input, using which components are built, followed by systems, software and finally application use-cases. The left most vertical i.e. Technology Provider, is common across all quantum verticals. In the subsequent steps, are organized in terms of computing, communications and sensing horizontals. Other stakeholders in this middle box include IT system integrators, full stack integrated systems providers and quantum security.

[10] Adapted from: The Quantum Value Chain Report, QETCI, Dec 2023.

2.4 Lessons from Global Best Practices

2.4.1 The importance of credible industry consortium like the Quantum Economic Development Consortium (QED-C)

The National Quantum Strategy[11] of the US has 3 components: (i) getting the science right, (ii) enhancing competitiveness and (iii) enabling people. The objective of the second component is to: "enhance competitiveness by accelerating technology development toward useful economic and mission application of QIS and working with international partners, while also protecting national security."[12] The QED-C[13] is an industry led consortium that was created to enable and grow quantum industry in the United States. The QED-C was established with support from NIST as part of federal strategy as called out by National Quantum Initiative Act of 2018.

The QED-C as part of its mission "brings government agencies together with industry to help accelerate the use of quantum technologies to address the needs of the government, including in health, defence, finance, energy and transportation."[14] It also contributes significantly by bringing institutions such as NIST and industry players on a single platform to help focus on developing standards. These standards are then adopted by industry, and since US industry is at the cutting edge, they invariably become global standards. This is particularly useful in fostering a robust supply chain and physical infrastructure needed for quantum technologies. While they also provide a perspective on workforce development more broadly, their focus presently is on skills needed for developing a robust quantum supply chain.

2.4.2 Inter-university Microelectronics Centre (IMEC) ecosystem[15,16]

IMEC was established in 1984 as a non-profit spin-off of KU Leuven with an initial **investment of Euro 62 million** by local Flanders government, with the goal of becoming a R&D major in microelectronics, and to become a leader in chip-based revolution at that time.

Power devolution and local government's autonomy: Reforms in Belgium in 70s and 80s empowered local government to be autonomous in areas including economy, innovation and international trade. This led to close collaboration of universities, industry and research institutes leading to technology innovation and technology-based business driving growth. This devolution of power also led to tech transfer activities allowing universities to own IP and to participate in seed funds.

IMEC Industrial Affiliation Programme (IIAP): Established in 1991, this program has been pivotal in developing a new business model through joint use of development costs, risks, development capabilities and IPs. Based on this scheme, any new project approved by IMEC – even those involving multiple industries, IMEC would support by sharing not only its knowhow but also its IP would become background IP for the project. In this model, the collaborators can have joint IP and add to the pool of common IP, but also has structural pathways to create exclusive IPs as well.

2.4.3 Synergistic academic, industrial and ecosystem policies in Japan

Japan is an industrial powerhouse which has leveraged R&D to drive growth since World War II. It has deep roots in semiconductors, robotics and automotive engineering which forms the core of its export-driven economy. Japan being highly industrialised,

[11] https://www.quantum.gov/strategy/
[12] https://www.quantum.gov/competitiveness/
[13] https://quantumconsortium.org
[14] https://thequantuminsider.com/2025/04/04/qed-c-executive-director-celia-merzbacher-named-a-2025-fed-100-winner/
[15] https://tech-innovation-europe-magic-left.fdiintelligence.com
[16] Odake and Tokumaru, "Model of Innovation System in Public Research Institutions: The cases of IMEC from Belgium and ITRI from Taiwan", PICMET 2012.

and vertically integrated economy works in its favour when a new technology like quantum computing emerges. That said, it being highly successful in adopting that technology and being leader in some aspects of it, requires more closer scrutiny of how it incentivises the ecosystem to develop and to succeed.[17]

2.4.4 **Drivers and enablers**

(i) Transformation in manufacturing and supply-chain: With manufacturing and supply-chain becoming highly complex, and with Japan being an incumbent leader in this space, there is a market need to solve this problem efficiently. These problems are good use-cases for quantum computing.

(ii) Japan's challenges in healthcare: Japan is ageing, and workforce is shrinking. This means that there is natural interest in problems such as drug discovery, improving diagnostics and to improving efficiency; at the same time, hospitals, pharmaceuticals and medical device manufacturing sectors are looking to advance its technology and solutions to meet the market needs. Again, quantum computing seems to intersect with this space positively.

(iii) Government a strong enabler: The government follows a multifaceted approach wherein multiple ministries collaborate and co-ordinate their efforts to sponsor research, aid commercialisation and help de-risk investments. They also have government backed consortiums that provide collaboration platforms for private sector, research labs and academia.

2.4.5 **Policies and initiatives**

(i) National Strategic Roadmap and careful planning tracking: Japan has been one of the early adopters of quantum computing since 2018-19 and has been developing and refining its national strategy since 2020.[18] They encouraged their existing manufacturers to expand into developing components for quantum industry, created a Quantum Hardware Test Center, enabling the components to be of global standard. Their national strategy now has evolved and has 3 phases – (i) foundational research, (ii) pilot implementation and (iii) broader commercialization. Additionally, their strategy is combined with very careful planning and deep review. Reviews are used not only to track progress but also to identify gaps where there could be targeted intervention.

(ii) Significant Government funding: Many Government bodies run specialised grant programs for quantum computing. Key aspect of this funding is that it not only supports domestic but also international ventures, provided they are of cutting edge or have commercial viability.

(iii) Supportive environment for startups: Many seed funds and incubator programs have been created and hosted in academia or in innovation hubs. They provide pre-seed funding along with business mentorship for startups to escape the so called "valley of death."

(iv) Favourable tax regime: Besides providing tax deductions for quantum companies, some local governments also provide subsidies or reduced facility costs for establishing research and manufacturing facilities.

(v) Balanced regulatory environment: The regulatory environment balances the innovation needs to move fast with societal need to be of high-quality. This is

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[17] https://onestepbeyond.co.jp/blogs/japans-quantum-computing-race-how-global-tech-firms-can-get-involved/
[18] https://www.ibm.com/quantum/blog/japanese-quantum-ecosystem

important and a difficult balance to find. Since the regulation also emphasises on quality, the Japanese startups and enterprises that meet these standards invariably meet other global standards. This enhances trust amongst potential clients globally.

(vi) Robust IP protection and legal environment: The system has an IP protection framework and the legal system that is strong and reliable, and conflicts are managed in a time-bound and efficient manner.

2.5 Ethics and governance in quantum era

Quantum computing is a fundamentally new model of compute that leverages the principle of quantum physics. The impact of quantum computing on society at large is still an open question. However, the technology is evolving quite rapidly and is at the threshold of quantum advantage. It is also a technology that will be working in consonance with existing classical computing resources. Given that there are ethical and governance challenges even with classical computing, quantum computing can possibly bring about new challenges and/or accentuate existing challenges, and therefore merits deeper consideration.

2.5.1 **Following are some of the ethical and governance[19,20,21] related questions that merits attention:**

(i) Standards for benchmarking and reproducibility of results: Quantum computing is still evolving benchmarks and standards in measuring the capabilities of its hardware and algorithms; this sometimes leads to mis-placed claims that undermines society's trust in the technology.

(ii) Potential to accentuate "digital" divide: There is a "digital" divide in the world that we inhabit today, within nations and amongst nations; quantum technologies at this point is expensive and is not affordable to large sections of populations; this can increase the gap between haves and have-nots, making it harder to bridge the divide. In quantum, the divide is more acute amongst nations at this time of development as only a few nation states and corporations have the wherewithal to develop the technology.

(iii) Data encoding and explainability: Quantum capabilities like superposition and entanglement provides novel ways to encode data, which can lead to ethical challenges beyond what is considered in AI ethics in classical data. Given the fundamentally probabilistic nature of quantum computing, there is an added complexity to already challenging problem of explainability in (quantum-powered) machine learning models.

(iv) Quantum data: Quantum sensing technologies are advancing at a rapid pace, and it is possible that there could be a time when the output from sensing could be quantum data. For instance, advanced sensors/nanobots could generate quantum signals from a patient's internal organs like heart as part of diagnosis. It is also possible that quantum memory could be realised in the coming years. While principles like no-cloning theorem ensures that the data cannot be copied, the data can however have longer lifetime due to quantum memory. Given this, would data governance principles require a relook in the context of quantum data?

[19] L.M. Possati, Ethics of Quantum Computing: an Outline, Philos. Technol. 36, 48 (2023).
[20] https://quantumzeitgeist.com/the-ethics-of-quantum-computing-considerations-and-challenges/
[21] World Economic Forum, Quantum Computing Governance Principles, Jan 2022.

(v) Patents to basic scientific discovery: It is likely that quantum computing will lead to new discoveries such as useful molecular structures, protein interactions and microscopic behaviour in complex materials. Patenting such fundamental knowledge can lead to further privatization of knowledge.

(vi) Lack of diversity in quantum workforce: An aspect of "digital" divide is lack of opportunity for sections of society that is marginalized or less privileged, leading to lack of diversity in quantum workforce. Proactive measures to ensure rural access to benefits from quantum technologies and encrypted communications, and support for quantum education in Tier II/ III cities, will be important.

While quantum computing is still evolving, it is doing so at a rapid pace. It is important that aspects of ethics and governance principles are considered now rather than after the technology is deployed at scale. It is also important that all stakeholders – government, industry, academia, non-governmental organisations, and society at large – participate in this important conversation to ensure common good wins while risks are mitigated. A national taskforce or regulatory framework similar to AI ethics initiatives, which could pre-emptively guide on the above aspects will be important.

3. QUANTUM TECHNOLOGIES: DISRUPTIONS, IMPACT AND RISKS

3.1 Key disruptions enabled by quantum technologies

Quantum technologies are poised to drive major transformations across various strategic sectors, with particularly strong implications for India's economy, security, and technological landscape. Below are the core areas where quantum technology is expected to generate significant disruption and opportunity:

3.1.1 Strategic sector applications

(i) **Defence and Intelligence**: Defence and intelligence sectors will experience the earliest and most profound impact from quantum technologies. Innovations include GPS-free quantum sensing for submarines, post-quantum and hybrid quantum key distribution (QKD) for secure communications, and advanced quantum-based computational models for optimization and computational fluid dynamics (CFD). These advances are critical to enhancing India's strategic security and promoting technological sovereignty in sensitive areas.

3.1.2 New applications across industries

(i) **Healthcare and Life Sciences**: Combining quantum sensing and computing can revolutionize medical diagnostics, drug discovery, genomics, and personalized medicine.

(ii) **Logistics and Supply Chains**: Quantum optimization can streamline complex logistics, leading to cost savings and efficiency improvements.

(iii) **Fintech**: Enhanced security and computational power can drive innovation in financial modeling, fraud detection, and data encryption.

(iv) **Chemicals, Petroleum and Mining**: Quantum solutions enable better resource exploration, material discovery, and process optimization.

3.1.3 Peripherals and global supply chain integration

(i) India must aspire to be a net exporter of quantum technologies through focused investment and favorable geopolitics, becoming an integral part of the global quantum supply chain

3.1.4 Quantum IT and software services

(i) **Service Export Opportunities**: As the global quantum economy expands rapidly in the coming decade, demand for quantum software and quantum-enabled IT services will surge. India, with its robust IT services and software sector, is uniquely qualified to capture a substantial share of the global quantum services market.

3.1.5 Creation of high-value Jobs

(i) Quantum technologies demand highly specialized skills in both manufacturing and algorithmic domains. Advancements in this domain will generate roles across research, manufacturing, and software—resulting in the creation of high-value, future-proof jobs that are essential for India's economic ascent.

3.2 Impact and risks across sectors

Quantum technologies' impact is broad and wide – from citizens to government. For citizens, mainstreaming of quantum technologies is likely to transform everyday life by reshaping education, healthcare, and job creation. This will fuel a surge of innovations leading to high-value jobs across research, manufacturing, software and services. However, the challenges to cybersecurity and data privacy increases as well as managing workforce transition in the context of quantum-enabled AI based automation-driven job displacement; these can be especially sensitive in growing middle-income country like India.

Quantum technologies can significantly augment governance by enhancing national security, economic resilience, and public service delivery. For strategic sectors—including defence, cybersecurity, and critical infrastructure—quantum capabilities can unlock offensive and defensive tools previously beyond reach. Further, they can enhance sustainable agriculture, optimise renewable energy integration, strengthen nationwide systems for emergency preparedness, transport planning, and fraud detection in welfare programs. These are possible only if policymakers have deeper understanding of these emerging technologies in order to craft relevant, forward-looking regulations and strategies; without this, India risks lagging in setting standards, safeguarding public interests, and leveraging quantum for developmental goals.

3.2.1 **Opportunities**

Quantum technologies present a generational opportunity for Indian industry to leapfrog into high-value, innovation-driven growth. As a greenfield sector, quantum offers India the chance to position itself as a global technology and knowledge economy, unlocking value across manufacturing, healthcare, logistics, finance, energy, and tech services. Early adoption in financial services, chemicals, pharma, and scientific research in the next 5 years—expanding to mainstream adoption 2035—can drive major productivity and competitiveness gains.

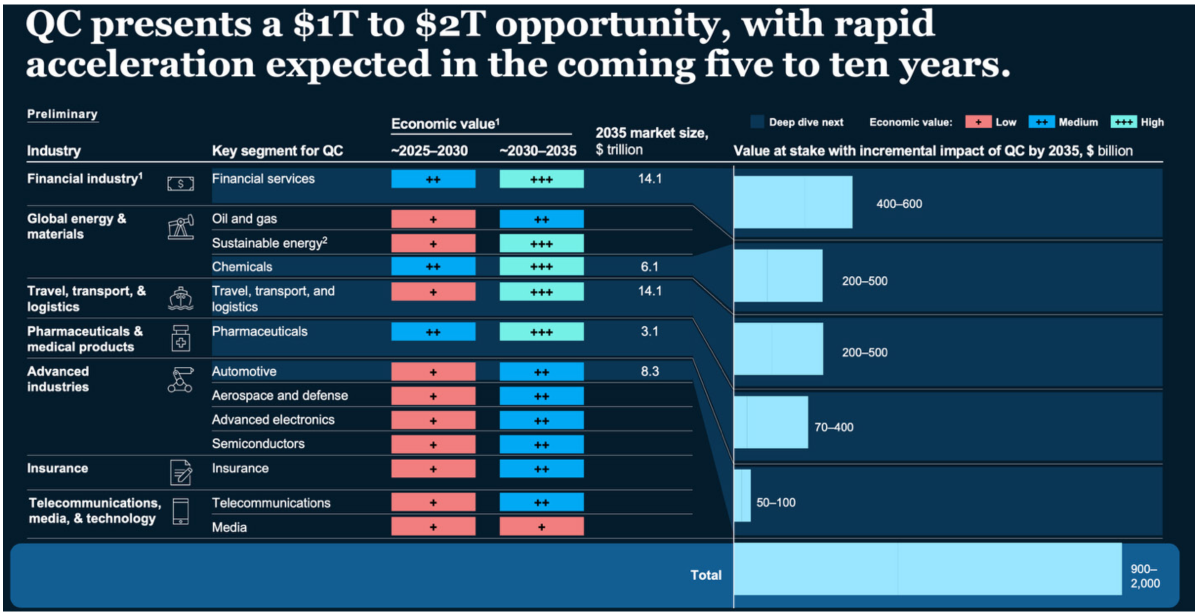


Figure 4: The value opportunity from Quantum Computing across sectors.[22]

In the Indian context, quantum technologies are expected to have significant impact across multiple sectors including agriculture, financial, healthcare, manufacturing and logistics and transportation (see Figure 5).

[22] McKinsey and Company, Quantum Technology Monitor, Apr 2024.

Estimated cumulative value added by quantum technologies across industries by 2030 (in USD B)

Low value — High value

Quantum technologies	Agriculture	Financial services	Healthcare and life sciences	Heavy industries*	High-tech**	Manufacturing	Public administration and defence	Telecom and broadcasting	Travel and transportation	Total by Technologies
Quantum computing	14–17	18–20	3.0–3.2	13–15	23–25	38–39	9–11	7–8	16–18	143-157
Quantum communications		22–24	0.2–0.6	1–2		3–4	25–26	7–8	1–2	59–66
Quantum materials			1.1–1.3		8–9	11–12		3.9-4.4		24–27
Quantum sensing	2–3		3–4	18–20	6–6		18–20	5–6	1–2	55–61
Total by Industry	17–20	40–44	8–9	32–36	38–41	52–55	52–57	23–26	18–22	280–310

Figure 5: Estimated value of quantum technologies in India by 2030.[23]

Quantum sensing (Figure 6), simulation, and computing will power breakthroughs in diagnostics, energy grid management, logistics optimization, molecular research, and materials discovery, while also catalyzing a vibrant startup and MSME ecosystem. This transformation could enable Indian companies to move up the global value chain and build new business models in cloud, HPC, and quantum-centric services.

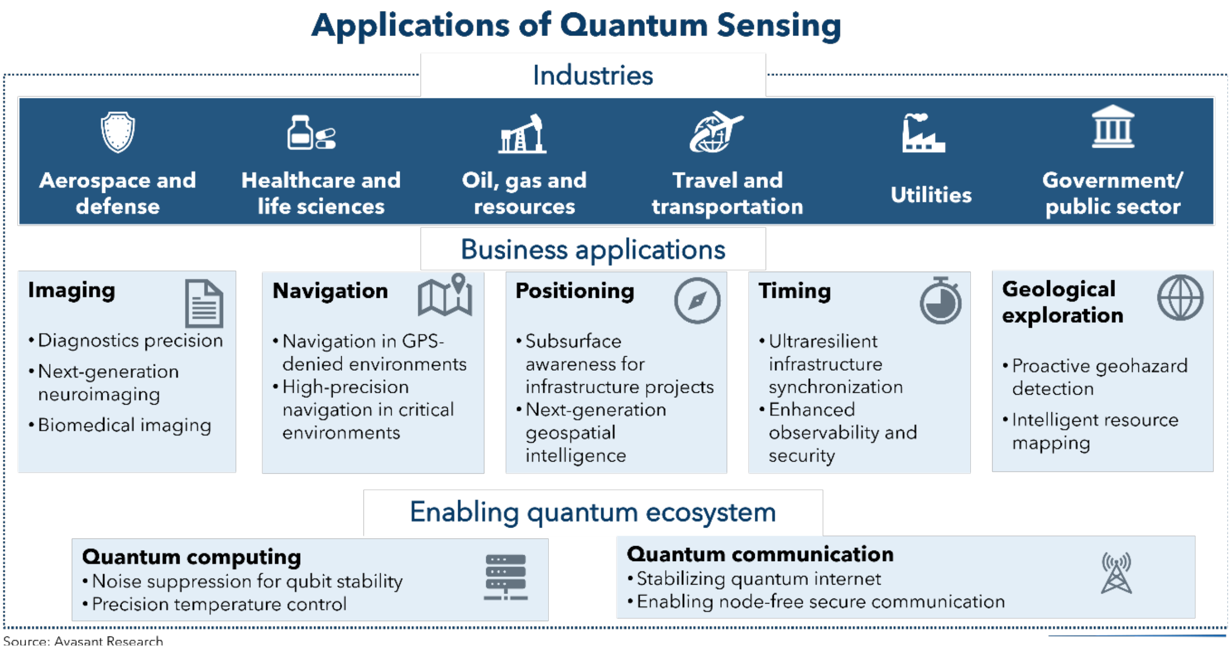


Figure 6: Potential applications of quantum sensing, where it is expected to provide substantial advancement over classical sensing in terms of precision and reliability.[24]

Some of the use cases where quantum computing can unlock value across these different sectors in India are listed below:

[23] NASSCOM-Avasant , "The Quantum Revolution in India", 2022.
[24] Avasant Quantum Series, Quantum sensing in business – what every enterprise leader needs to know, Jul 2025.

(i) Airlines.[25,26] India's aviation industry has seen remarkable growth over the past decade. Domestic air travel is projected to double, reaching 300 million passengers by 2030, up from 152 million in 2023. The number of operational airports has risen from 74 in 2014 to 157 in 2024, with a target of 350–400 by 2047. This rapid expansion introduces complex operational challenges, demanding greater efficiency, cost optimisation, and sustainability. Quantum computing holds promise in addressing these needs—by resolving operational disruptions, optimising network planning, personalising customer experiences and improving revenue management.

(ii) Renewable Energy. Government of India is making a focused effort around renewable energy with the country's ambitious renewable energy target of achieving 500 GW from non-fossil sources by 2030. As renewable energy sources expand and consumption patterns evolve, this throws new challenges in energy demand forecasting, optimisation and storage. Integrating renewable energy into the grid requires advanced algorithms that can process weather forecasts, grid dynamics, and consumption patterns to accurately predict supply and demand. Optimising operations and energy storage involves solving complex, real-time, multi-variable problems that go beyond the capacity of traditional methods. These kinds of problems are best suited for quantum computers to solve given the constraints of classical computing.

(iii) Logistics. India's logistics sector is undergoing a major transformation under the PM GatiShakti initiative[27], which integrates infrastructure planning across 44 central ministries and 36 states. With an investment of INR 11.17 lakh crore across 434 key projects, and over 91 multimodal cargo terminals already operational, the initiative is enhancing connectivity and reducing bottlenecks. The Indian freight and logistics market is projected to reach USD 484 billion by 2029 (from USD 317 billion in 2024), while logistics costs—historically 13–18% of GDP—are being streamlined toward the global benchmark of 8%.

Quantum computing can significantly enhance India's logistics sector, especially in the context of the PM GatiShakti initiative. By solving complex optimisation problems at scale, quantum algorithms can potentially improve multimodal route planning, reduce transit times, and cut logistics costs. They can optimise warehouse and cold-chain operations, enhance demand forecasting, and support real-time decision-making across India's vast transport network. As India invests in infrastructure and aims to reduce logistics costs to global benchmarks, quantum computing offers a powerful tool to boost efficiency, resilience, and competitiveness in the logistics ecosystem.

(iv) Banking & Financial Markets.[28] Quantum computing has the potential to revolutionise the banking and financial markets by tackling complex problems that are currently computationally intensive. In trading optimisation, quantum algorithms have the potential to analyse vast datasets to identify optimal trading strategies and arbitrage opportunities in real time, far surpassing classical models. For risk profiling, quantum systems can simulate a broader range of market scenarios and asset correlations, enabling more accurate assessment of portfolio risk and stress testing. In customer targeting and prediction, quantum machine

[25] https://www.reuters.com/business/aerospace-defense/global-airlines-bet-india-travel-boom-2024-06-14/
[26] https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=152143
[27] https://www.business-standard.com/economy/news/pm-gati-shakti-logistics-policy-to-push-india-s-world-bank-ranking-report-125020500981_1.html?utm_source=chatgpt.com
[28] The Quantum Decade, IBM Institute of Business Value.

learning can uncover deeper behavioral patterns, leading to more precise credit scoring, fraud detection, and personalized financial product recommendations.

(v) **Chemicals and Petroleum**. Quantum computers can potentially simulate molecular interactions to accelerate the development of new catalysts, surfactants, and chemical products, while also optimizing feedstock routing, refining processes, and reservoir productivity.

(vi) **Electronics**. Quantum simulations can enable the discovery of advanced materials, leading to smarter manufacturing and innovative product designs.

(vii) **Healthcare and life sciences**. Quantum algorithms can enhance diagnostic accuracy, support precision medicine, and accelerate drug discovery—especially in modeling protein folding and small-molecule interactions.

(viii) **Insurance**. Quantum machine learning can revolutionize customer and risk classification, improve catastrophe and mortality projections, and refine premium pricing models.

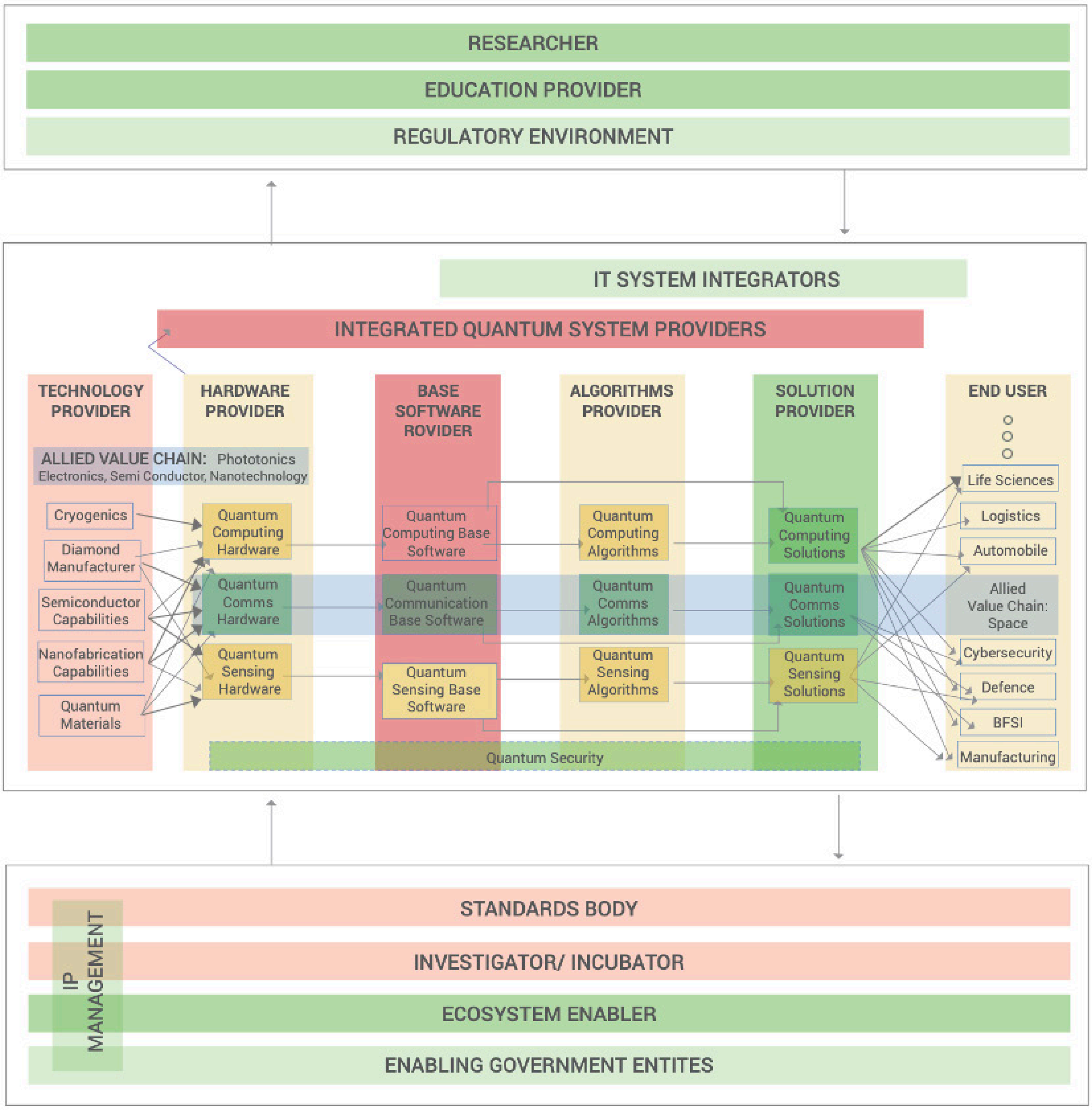
(ix) **HPC-Quantum to quantum-centric supercomputing.** HPC and cloud infrastructure space will need to factor in quantum technologies into the mix. It will have to figure out how to map workflow into CPUs, GPUs and QPUs managing cost, quality of solution and efficiency trade-offs. In the coming years, quantum communication amongst clusters within a center, between centers, eventually leading to quantum internet, requiring novel solutions and businesses to emerge.

3.2.2 **Risks**

The disruptive nature of quantum can pose significant challenges for industry. Quantum computing could upend cybersecurity, rendering current encryption obsolete and creating systemic vulnerabilities across financial, energy, and critical infrastructure networks. The rapid infusion of quantum-enabled AI may accelerate automation, pressuring traditional jobs and requiring costly reskilling. For businesses, the capital intensity, talent shortages, and uncertain timelines of quantum maturity could lead to stranded investments if strategies are poorly aligned. Navigating these risks will require coordinated policy, industry collaboration, and early capability-building to ensure Indian industry captures value rather than gets disrupted.

4. INDIA'S POSITIONING: CURRENT SITUATION ANALYSIS, STRENGTHS AND BARRIERS

4.1 Current State of India's Quantum Value Chain



- **Dark Green** - Established
- **Light Green**- Advanced
- **Orange** - Building Up
- **Yellow** - Early Efforts
- **Red** - No presence
- **Blue -** Allied Value Chains – not evaluated

Figure 7: Current state of India's value chain.[29]

[29] Adapted from: The Quantum Value Chain Report, QETCI, Dec 2023.

In the complex space of quantum value chain, India presents a mixed picture (Figure 7). Amongst the key verticals, quantum communication shows relatively stronger performance across most aspects of the value chain. Quantum sensing seems to have reasonable footprint while quantum computing has definite gaps. Across the board, India needs to pay significant attention to technology supply chain dependency, limited investment in end-to-end system development, especially in building indigenous quantum hardware and foundational software stacks that interface directly with hardware.

To become globally competitive, India must urgently:

(i) Strengthen its hardware-software co-design ecosystem.

(ii) Invest in standards development, and build cross-sectoral consortia to shape the quantum technology landscape.

(iii) Create confidence-building mechanisms for industry and investors through regulatory clarity and long-term policy signals.

(iv) Scale up R&D, incubation, and capital flows across the entire quantum stack—from materials and devices to algorithms and applications.

Table 2 shows the SWOT analysis of Indian ecosystem in quantum technologies and highlights some of the key points.

Strengths	Weaknesses
• Over 91,000 STEM graduates • Strong and mature IT services sector • State-led R&D hubs (QuRP, AQV) and competition among states • Kernel of military-industrial complex emerging through programs like iDEX • Large domestic market, growing economy and digital infrastructure (DPI)	• Larger gaps in quantum computing - hardware, system integration and software stack • Import dependence on peripherals and materials • Low investment in basic science (0.65% of GDP), low quality of research (~10%) and IP share (not in top 10) • IP governance needs strengthening • Skills gap in cryogenics, optics, microwave systems and techno-business talent • Procurement and audit processes are complex and time consuming

Opportunities	Threats
• Potential trillion dollar quantum economy that is still green-field • Geo-strategic need to diversify dependence on materials and peripherals away from China • Quantum technologies can fundamentally transform healthcare, energy, logistics, finance, manufacturing • Defence adoption to expand and deepen military-industrial complex	• China's investment in quantum and dominance in materials • IP ownership and talent loss due to redomiciling of startups • Risk-averse capital, overregulation and policy uncertainties slowing adoption • Rule followers if Indian stakeholders don't participate actively in global standards body • Tax uncertainties and policies limiting cross-investment in startups across countries reduces investor confidence

Table 2: SWOT analysis of India, its ecosystem and capabilities.

4.2 Analysis on key success imperatives

4.2.1 **Materials and supply-chain**

Quantum technologies depend on many advanced and rare materials, which are not easily available locally. As an illustration, Figure 8 shows the materials used by different quantum technology components and their dominant source countries in the supply chain of The Netherlands.

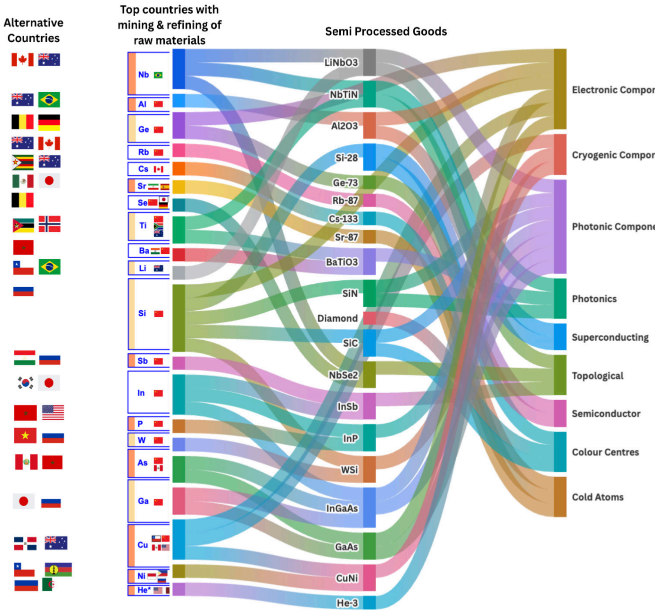


Figure 8: Overview of the materials that are required for quantum technology R&D in the Dutch ecosystem.[30,31]

[30] U. Mans, J. Rabbie and B. Hoppman, Critical Raw Materials for Quantum Technologies: Towards European technology sovereignty in an emerging industry, Ver 1.0, 27 Nov 2023.
[31] Office of the Principal Scientific Advisor to the Gov. of India, "India's International Technology Engagement Strategy for Quantum Science, Technology and Innovation," 1st ed., Apr 2025.

While this is not specific to India, their general landscape of materials and sources will likely look not too different. To ensure a stable supply of such materials as India looks to scale in quantum technologies, it will be critical to develop a strong and deep understanding of the supply chain and ensure resilient trade and economic ties with nations and entities on which there will be dependencies, to reduce bottlenecks and vulnerability to market and global dynamics. It will be important to also develop local sources of critical and strategic materials, and refinement and processing capabilities. It is to be noted that China has a dominant presence both in raw materials and in processing.

A higher-level view of dependency at technology level is shown in Figure 9. US has a full stack presence and is in the pre-eminent position in this space. It is to be noted that China is not far behind and has strong presence in majority of those supply chain. Peripheral manufacturing in the context of quantum technologies usually alludes to subset of this supply chain, i.e. control, device and components.

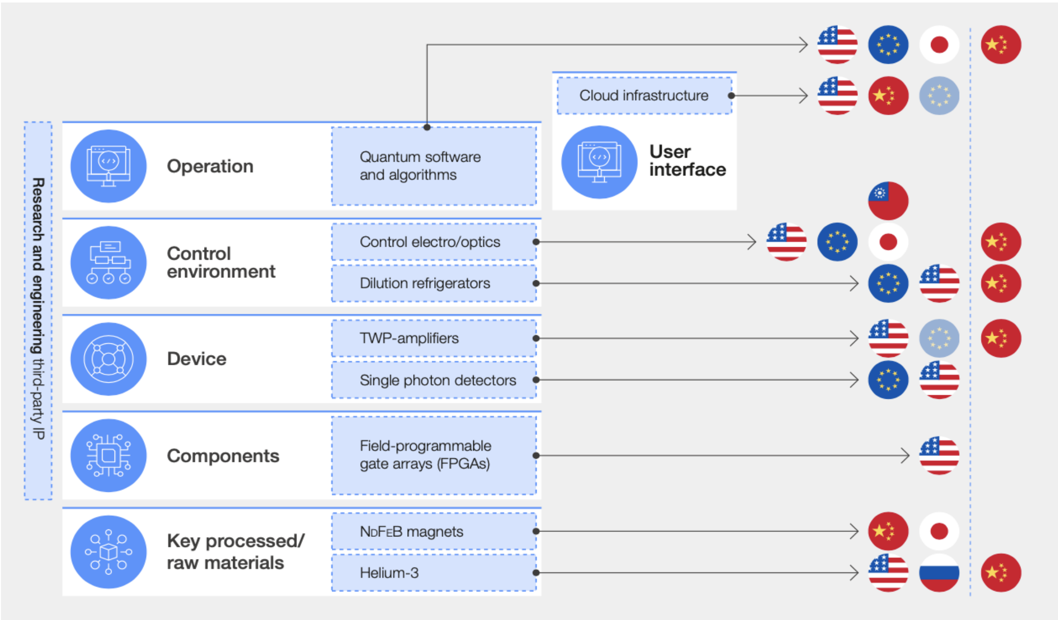


Figure 9: Quantum technologies supply chain. [32,33]

4.2.2 **Investments**

Investment into quantum technologies should be considered holistically – both public and private. In terms of public investment, India features amongst the top countries in the world (see Figure 10). It is important to note, however, that the difference in public investment between India and the top 3-4 countries is quite substantial, especially when compared to China that has invested about USD 15.3B[34] compared to India's USD 0.7B.

On private investment, the US is by far the leader. Figure 11 shows the private investments by country as well as the number of startups by country. It is to be expected that US leads the number of startups in this space. It is interesting to note that India features highly in the number of startups but not in the list on investment. This does raise the question on capacity of Indian startups to perform competitive technology development and market scaling.

[32] World Economic Forum, Quantum Economy Blueprint, Jan 2024.
[33] Riekeles, Georg E., Quantum technologies and value chain: Why and how Europe must act now?, European Policy Centre, Mar 2023.
[34] https://www.mckinsey.com/featured-insights/sustainable-inclusive-growth/charts/betting-big-on-quantum

It is worth noting that countries such as the US, Canada and UK have a significant portion of investment into quantum technologies coming from private source, with a healthy balance between public and private funding. In fact, in China while private investment is estimated at a non-trivial USD 1B, the public funding however is estimated to be the highest in the world. India can benefit substantially from much higher private investment that is in balance with public funding, while at the same time seeing much higher levels of public funding.

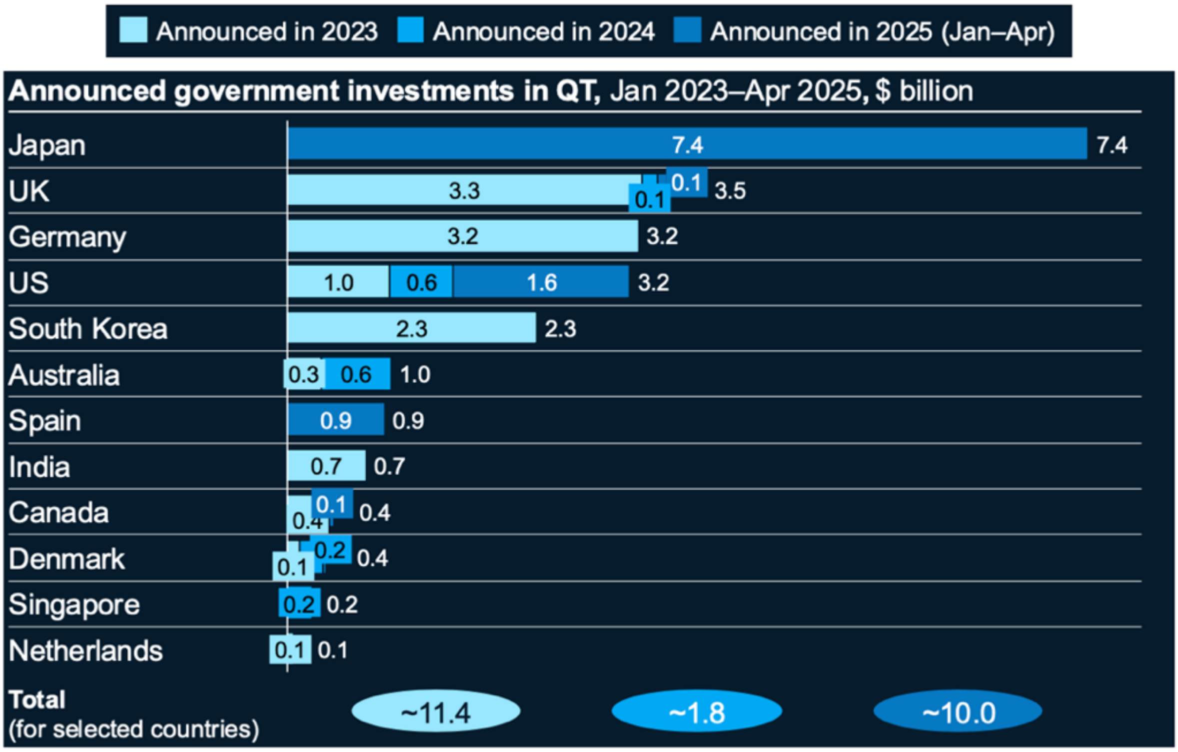


Figure 10: Government funding announcements indicate opportunity for India to grow investment. [35] **(Note: this captures announcement since 2023; China doesn't feature here as it announced it's quantum investments in 2022).**

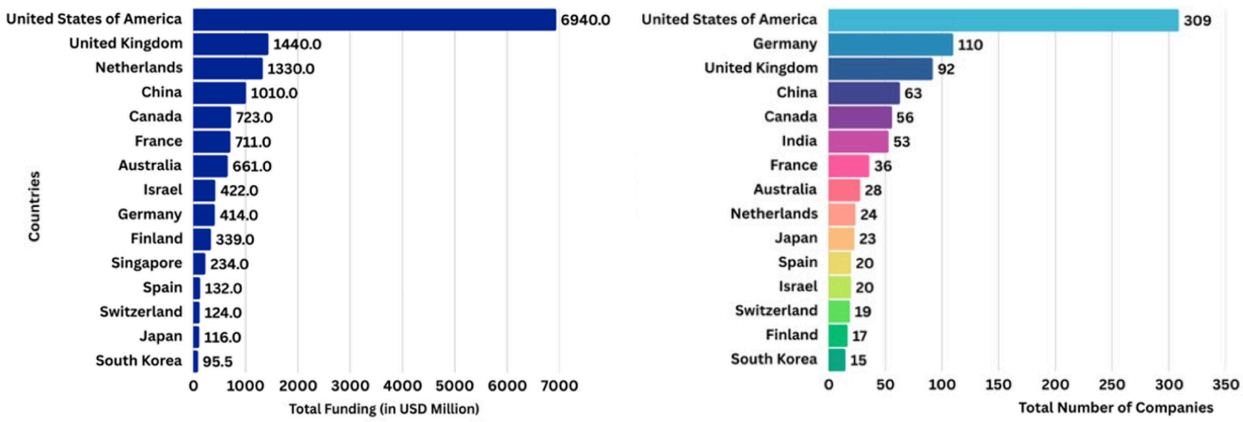


Figure 11: Private investment and startups by country: (a) investment, and (b) number of startups. [36]

[35] McKinsey and Company, Quantum Technology Monitor, Jun 2025.
[36] Office of the Principal Scientific Advisor to the Gov. of India, "India's International Technology Engagement Strategy for Quantum Science, Technology and Innovation," 1st ed., Apr 2025.

4.2.3 **Research**

Table 3 shows percentage of publications from India in different quantum verticals that are in top 10% globally.[37] While India has a good quantity of publications, the quality of those publications is on average about 10%. This metric needs to increase substantially for India to become a leader.

Technology area	% of Indian publications in top journals
Quantum computing	9.7%
Quantum communications and cryptography	9.4%
Quantum materials and devices	12%
Quantum sensing and metrology	8.7%

Table 3: Quality of research publications in quantum technologies from India. [38]

Figure 12 shows the share of quantum-relevant scientific publications by country for 2023 and 2024. China is by far the leader with US and EU being distant second, and China is extending the gap further. The share of authors from India contributing to quantum-relevant publications in 2023 and 2024 has remained flat at about 2%. While India does feature in the top 10, China's contribution is over 20X that of India's in 2024.

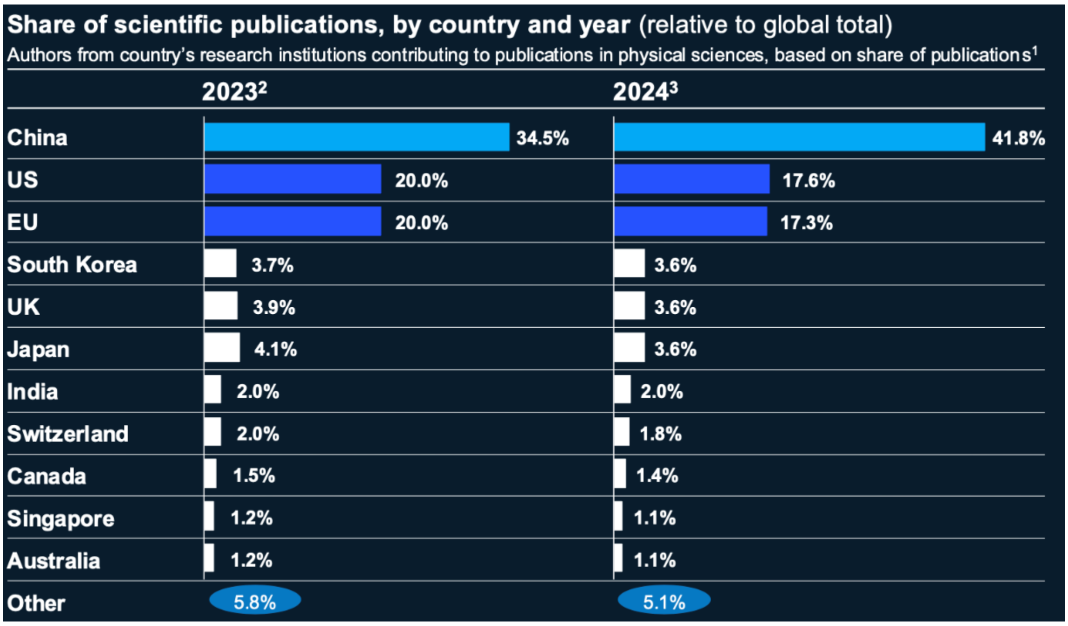


Figure 12: Share of authors from country's research institutions contributing to quantum-relevant publications for years 2023 and 2024. [39]

[37] Considers top journals and the number of citations.
[38] Office of the Principal Scientific Advisor to the Gov. of India, "India's International Technology Engagement Strategy for Quantum Science, Technology and Innovation," 1st ed., Apr 2025.
[39] McKinsey and Company, Quantum Technology Monitor, 2025 (sourced from Nature Index).

4.2.4 **Patent ownership**

The patent profile for India, in proportion to the investment made, seems reasonable (Figure 13 (a)). Figure 13(b) shows the patents organized by the country of ownership across all verticals. It is to be noted that India does not feature in the top 10 in this list.

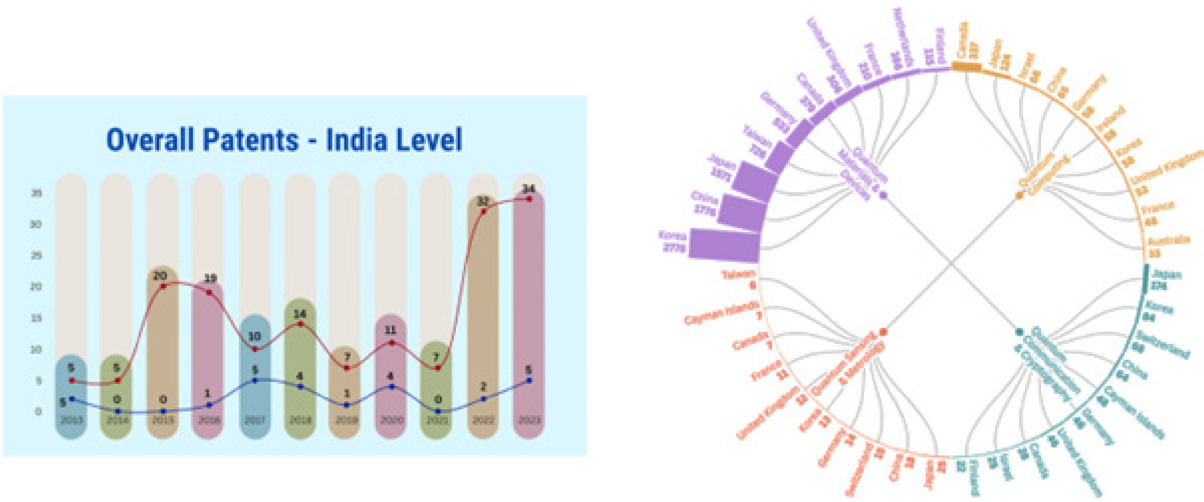


Figure 13: Patents and ownership countries: (a) Patents in India, (b) Patents by owning countries across verticals. [10]

4.3 Enablers and unlocks needed

4.3.1 **Skills: Scientific, Engineering and Techno-Business**

Quantum technologies have skill requirements spanning across many disciplines: intricate design and manufacturing of quantum hardware, such as quantum processors and photon detectors, to developing sophisticated quantum software and algorithms necessary for practical applications. Specialists in these areas must possess deep knowledge of quantum mechanics, quantum information theory, and quantum cryptography, which enables them to understand and develop the theory and applications of quantum technologies. At the same time, there is a need for a workforce with a variety of supporting skills, such as proficiency in classical computing, materials science, engineering, cybersecurity, data science, sales, marketing, and business development. These supporting skills are crucial for integrating quantum technologies within existing systems, to develop real-world applications and to connect market needs to these emerging technology products and scale business models. It is expected that there will be a workforce requirement of 600,000 new positions worldwide by 2040.[40] If India is in the top few quantum economies, we may expect roughly 20-25% of this workforce deployment to be in India.

[40] Venegas-Gomez, Araceli, "The quantum ecosystem and its future workforce: A journey through the funding, the hype, the opportunities, and the risks related to the emerging field of quantum technologies", Photonics Views 17.6 (2020).

(i) Strengths

India has had a sustained research workforce in the areas related to quantum technologies, with an estimated 170 professors[41] in these areas. Many of these professors have deep domain skills at global competency levels, and regularly publish new research in these areas, which requires mentoring students and researchers. There is a strong software engineering and computer science skill capacity in India given the strength of the IT sector. India stands second in terms of number of graduates in quantum technology relevant fields. Out of an estimated 367,000 graduates, it is estimated that 91,000 are in India. The estimated distribution across countries is as follows:[42]

Country/Region	# of graduates (in 1000s)
European Union	113
India	91
China	64
United States of America	55
Russia	26
United Kingdom	18

India has one the leading user base of quantum computing in the world. Figure 14 shows the users of IBM's quantum computing systems by country. India stands at number two right after the US, indicating the tremendous interest and awareness in India among learners. This is despite having relatively few initiatives and programs for quantum computing education in the country. While this data is limited to IBM systems, it does indicate the ability of Indian learners and professionals to skill up on quantum software development.

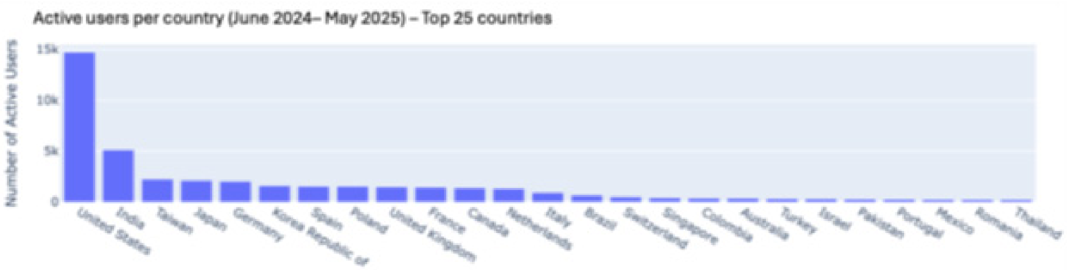


Figure 14: Active users of IBM Quantum systems over the period of June 2024 to May 2025. Source: IBM.

If we take a deeper look at the actual usage of the quantum systems, we see another aspect to this. Figure 15 shows the usage in hours, and we see that in this case India stands much lower. When coupled with the number of active users, the finding here is that while there are many Indians who are skilling up to program quantum computers, they are not following through to meaningful, deeper usage beyond the initial education levels likely because of the scarcity of funding and projects to motivate this deeper usage. This indicates the need for India to ensure that there is an environment that funds and supports deeper skilling and productive algorithm development expertise in our learners and researchers.

[41] NITI Frontier Tech Hub, Quantum Computing: National Security Implications & Strategic Preparedness, Mar 2025.
[42] McKinsey and Company, Quantum Technology Monitor, Apr 2024.

It further indicates that access to quantum hardware is the limiting factor and strategies need to be evolved that democratizes access to latest hardware.

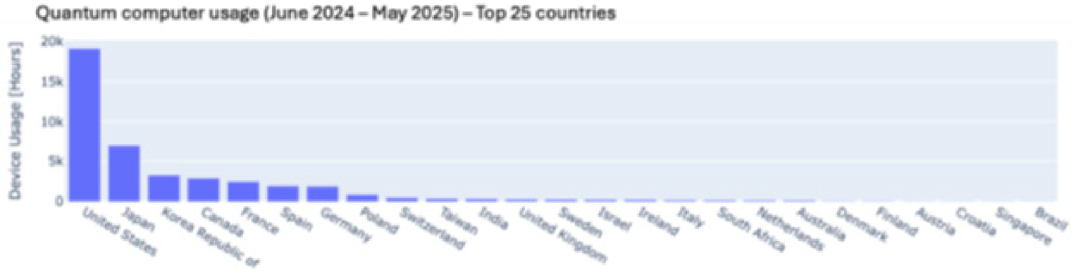


Figure 15: Quantum system usage in hours over the period of June 2024 to May 2025. Source IBM.

(ii) Unlocks needed

Need for much more scientific, technological, and techno-business skill breadth and availability.

These skills need to be built across the four domains of quantum technologies. They are often multi-disciplinary and include different disciplines like physics, material science, computer science, electronics engineering, communication engineering, electrical engineering, mechanical engineering, etc. Quantum technologies also require new techno-business capabilities in developing business use cases for real world applications, and marketing quantum technologies across different sectors in industry. Currently, India's educational focus with quantum technologies is on advanced degrees to power R&D capabilities; while the number of graduates is high, there is insufficient inter-disciplinary breadth in the workforce, a scarcity of manpower in specialized engineering skills with *cutting-edge expertise and experience*, and insufficient access to techno-business professionals that can help connect lab-to-product-to-market. In addition, there is also a need for a workforce with practical skills in working with cryogenics systems, microwave electronics, and fiber optics – all of which will be critical within the next few years.

Limited funding and resource constraints in education. A limited funding for education and training programs, coupled with a shortage of qualified instructors and infrastructure, makes it difficult to scale-up the demand for industry ready workforce. There is a need for increased funding to ensure that public and private engineering and science colleges in India are ready for meeting the demand for a workforce skilled in quantum technologies. Nation-wide digital platforms like SWAYAM and sponsored labs in regional NQM hubs can fast-track the training infrastructure.

4.3.2 **Industry: readiness, investment and adoption**

(i) Strengths

Indian IT services companies are positioned well and are prepared for quantum computing opportunities. IT services majors have invested in quantum computing and have both trained resources and have programs to scale out the training for more engineers. The Infosys Quantum Living Labs, TCS Quantum Computing Lab, HCL's Q-Labs, Wipro's MoU with Tel Aviv University, LTIMindtree Research – Quantum are some examples of IT services majors having Center of Excellence (CoE) internally, demonstrating their forward-looking investments.

Indian market, industry and global capability center (GCC). India is a large market and is keen to leapfrog technology cycles. There is an opportunity in the medium term to test, improve and benefit from quantum technologies. There is also the possibility of integrating quantum computing related technologies into India's robust DPI. India can become a one stop destination for global multi-national corporations (MNCs) for R&D in quantum technology as India houses more than 1,800 GCCs for MNCs.

Efforts in linking strategic sector with startups have started, for example the Innovation for Defence Excellence (iDeX) scheme by the Ministry of Defence.[43] The iDeX scheme aims to

- facilitate rapid development of new, indigenised, and innovative technologies for the Indian defence and aerospace sector, to meet their needs in a shorter time span,
- create a culture of engagement with innovative startups, to encourage co-creation for defence and aerospace sectors, and
- empower a culture of technology co-creation and co-innovation within the defence and aerospace sectors.

With a budget of about INR 498 cr, that allows grants of up to INR 10 cr to startups and MSMEs along with a partner incubator program, the iDEX scheme is a definite step in creating a positive flywheel of innovation-to-scale between the defence sector and startups. This can also enable some of the quantum technology startups to harden their products and develop a business. While this is a very positive start, much more can be done to increase such investment and flywheels not just with defence sector, but many other parts of the public sector.

State-level initiatives to incubate quantum R&D and attracting private investment exist. Several Indian states have created initiatives and funding schemes for quantum technology R&D and even for creating quantum ecosystems and economy. For example, Karnataka created the Quantum Research Park (QuRP)[44] at IISc as a CoE in the domain of quantum technologies. QuRP is setting up infrastructure consisting of equipment and instrument cluster, which can be shared nationally for research. It organizes internships and skilling programs and develops industry and startup collaborations with academia. More recently, Andhra Pradesh has launched a Amaravati Quantum Valley (AQV) Tech Park with an ambitious agenda[45] of creating a quantum technologies based ecosystem of research, development and commercial activity in Andhra Pradesh. This facility plans to have a Living-Lab Infrastructure that integrate quantum computers, QKD fibre links, and deployable sensor platforms to enable pilots across sectors like health-tech, BFSI, logistics, defence, and space. AQV is partnering with IBM, Tata Consultancy Services and L&T to deploy IBM's most powerful quantum computer[46] by 2026 and grow a partnership with industry and academia, for quantum algorithms research and at accelerating domestic R&D and capacity building in quantum technologies. Other states like Telangana have also been active in developing initiatives and charters for quantum technologies.

[43] https://www.ddpmod.gov.in/offerings/schemes-and-services/idex
[44] https://iqti.iisc.ac.in/quantum-research-park/
[45] Andhra Pradesh G.O.Ms.No.23, ITE&C Department, dt:07.07.2025, Quantum Valley Declaration.
[46] IBM Quantum System Two

Patient funding support to be initiated by Government of India via the Research Development and Innovation (RDI) Fund. The RDI fund scheme, approved by the Union Cabinet of India in 2025, is described as having "been designed to overcome the constraints and challenges in funding of private sector and seeks to provide growth & risk capital to sunrise and strategic sectors to facilitate innovation, promote adoption of technology and enhance competitiveness."[47] This will surely provide a new and much needed catalyst for large scale private investment into deep tech startups, including quantum technology startups.

(ii) Unlocks needed

Indian industry is likely to take 3-5 years for wider quantum computing proficiency and capacity. India has not yet witnessed a robust rate of adoption of cutting-edge quantum technologies. Indian industry is cautious and waiting to see more tangible benefits before adopting quantum computing. The challenges for adoption include (i) cost of quantum computing, (ii) lack of commercial use-cases, (iii) AI gaining more mind-space, (iv) industry just getting started now, (v) unfavorable ROI and (vi) geopolitical uncertainty. Most of the challenges listed (except last one) should be addressed in the medium term.

If we look at the number of large enterprises who are members of the IBM Quantum Network, which has a 200+ strong organizational membership, we find the following:[48]

Country	# of enterprises using IBM Quantum for research
Canada	4
Japan	14
Korea	3
Spain	4
Switzerland	2
United States	3

While this is surely not complete data of industry research in quantum technologies, it is however a proxy indicator to note that there is opportunity for much more involvement of Indian industry in quantum R&D, especially around algorithms development tied to business use cases.

Strategic sector engagement with the private ecosystem is limited. While quantum technologies have progressed leaps and bounds and are at the precipice of deployment in all technologies to different degrees, it however needs initial adoption that can offset the risk for private investors. This invariably is the strategic sector as they have the outlook, funding and wherewithal to engage with a forward-looking technology. For instance, DRDO's qualification systems can be very useful for startups to validate their products; this is especially true for quantum sensing and metrology as most of their applications are in the strategic sector. Challenges however include lack of rationalization of procurement processes, complex audit requirements, and lack of different zones of engagement within strategic labs that provides access to private players and can facilitate deeper collaboration. Further, there is a need to develop institutional pathways like grants and challenges to a much greater scale than present to incentivise best solutions to reach intended customers.

[47] https://www.pib.gov.in/PressReleasePage.aspx?PRID=2141130
[48] Source: IBM.

Accessing global markets for Indian companies is hard. Deep tech startups in India have a challenge in that the biggest market for their product is typically in the US or Europe. This limits startups in both development lifecycle – as it is hard to find an alpha customer who can help in product-market fit – as well as in scaling out their deployment and revenue. The limitation is credibility in deep-tech space as well as not having deeper network in the market ecosystem.

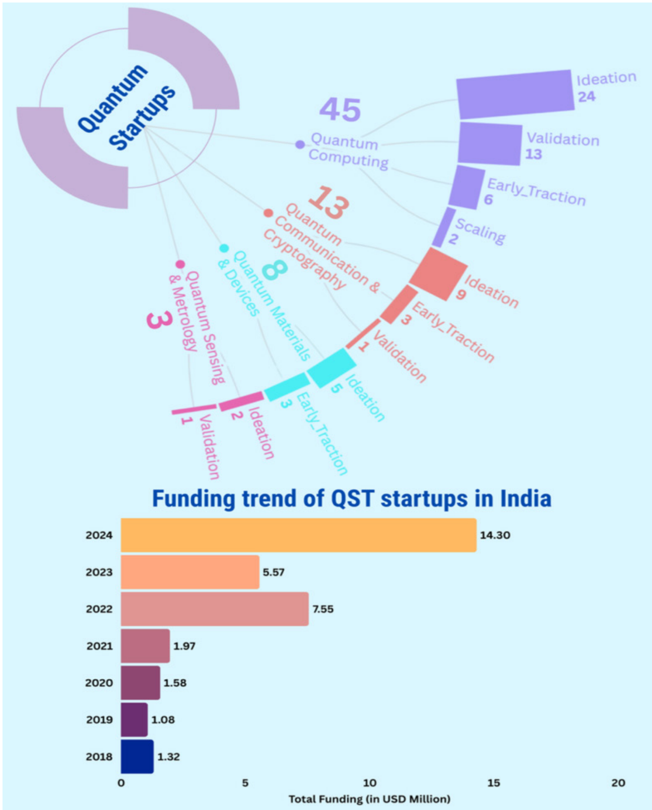


Figure 16: Quantum startups and investment in India. [49]

Private capital is risk averse and Private investment in research is very limited. Private capital and investment in India is presently risk averse and needs a defined pathway to revenue; this necessarily limits the time-horizon for funding and returns. Compared to the leading countries, India's private sector investment is extremely low within enterprises and on the startup side it is spread very thin across the large number of startups. These startups will need much more investment and patient capital, in order to develop differentiating technology and globally competitive products, and to grow into global market leaders. As we can see from Figure 16, many of the Indian startups are still in Ideation or Validation phase at this time and have a long journey to build traction and scaling. Large companies that are becoming globally competitive and are technology driven also need to invest much more in research.

Limited presence of local peripherals and component producers. Research and development in quantum technologies has a critical dependence on the supply of a variety of components and peripherals, such as cryogenic systems and electronics, high-end electronics, optics and opto-mechanics, among others. Today, the research labs and startups in India working on quantum technologies

[49] Office of the Principal Scientific Advisor to the Gov. of India, "India's International Technology Engagement Strategy for Quantum Science, Technology and Innovation," 1st ed., Apr 2025.

largely depend on external suppliers for such components and peripherals; for example, Thorlabs is a dominant provider of optical peripherals. This means that they suffer from both high procurement costs and overhead, long lag times between requirement and actual use, and lack of local workforce that can provide integration and maintenance support. Unless India can develop a local manufacturing ecosystem for at least a portion of these components and peripherals, this will be a key barrier to scaling.Colorado state[50] in the US serves as one state-level example of how an ecosystem for such peripherals development can be setup, which is creating a positive flywheel with the rapid growth of quantum computing startups in that state.

Regulatory requirements especially for manufacturing sector is too steep. There are multiple systemic barriers for someone doing experiments and/or advanced manufacturing – be it peripheral or core technology. It includes: (i) taxation policies that increases cost significantly, making the product uncompetitive, (ii) importing components or tools from outside is both time-consuming and requires significant bandwidth, (iii) tax uncertainties – especially arbitrariness and lack of formal process for determining taxes – increases investment risk.

Foreign investment in India and Indian investment globally has policy constraints. Greater foreign investment in Indian startups builds a stake in the success of those startups and for those startups to have greater access in investors' markets. Indian investment globally can lead to greater technology and knowledge sharing opportunities, and for advanced collaboration with Indian entities. India should encourage more cross-investments in cutting edge technologies and should not be viewed from narrow ownership lens; rather it should be viewed from technology advancement and skill enhancement prism; these will enable greater economic value-unlock in the future.

4.3.3 **Ease of doing research and lab-to-market**

(i) Strengths

Anusandhan National Research Foundation (ANRF). Established through an Act of Parliament, ANRF Act, 2023, ANRF will "provide high-level strategic directions for research, innovation, and entrepreneurship in the fields of natural sciences, including mathematical sciences, engineering and technology, environmental and earth sciences, health and agriculture, and scientific and technological interfaces of humanities and social sciences. Anusandhan National Research Foundation (ANRF) has been established to promote research and development and foster a culture of research and innovation throughout India's Universities, Colleges, Research Institutions, and R&D laboratories."[51] This is a promising structural change to bring much higher focus on strategic research and to foster a culture of research and innovation in India.

The Ministry of Finance of the Govt. of India has recently eased procurement rules for scientific research, making it easier for researchers, who rely on government funding, to procure equipment and consumables for their research and empowering the hosting institutions more to enable local decision making.

India has made progress in beyond-lab validation and deployment of some quantum technologies. There are several startups with meaningful products that are beyond the lab stage and early customers in India and globally. Some examples are QNu Labs for quantum communications, BosonQ Psi for quantum algorithms,

[50] The Quantum Insider, How to Build a Quantum State: Inside Colorado's Strategy for a Quantum-Ready Public, Apr 2025.
[51] https://serb.gov.in

Pristine Diamonds for high quality diamonds for quantum sensing, among others. In quantum communications, India is one of the few countries that has performed long-range demonstration of quantum-key distribution (QKD). Raman Research Institute (RRI) first demonstrated free space entanglement based QKD in 2021, and then between a stationary source and a moving receiver in 2023. Since 2021 ISRO and DRDO have demonstrated additional progress and very recently IIT Delhi demonstrated free-space QKD over 1 km. In 2023, IIT Delhi demonstrated trusted-node fiber-based QKD over 380 km. However, at the same time US has demonstrated fiber-based QKD of over 1,707 km[52] and China has reached 1,002 km[44]. China has set up the world's largest quantum communication network spanning much of the nation with a quantum industry ecosystem of research institutes and firms leveraging it.

(ii) Unlocks needed

Funding for scientific research remains low in India. India investment in scientific research is relatively low though in recent years it has made great strides in establishing missions and initiatives in targeted areas, such as with the National Quantum Mission (Figure 10). As per the UNESCO Institute of Statistics data published on the World Bank Open Data platform[53], India ranks approximately 53rd on this measure with its 2020 spend of 0.65%. As a reference, Republic of Korea spends 5.2%, the US 3.6%, China 2.6% and Brazil 1.15%. For example, EU has been funding basic science significantly and consistently over a long period of time (Figure 17); this sustained commitment is because breakthrough quantum technologies require deep theoretical advances along with applied development efforts. The quantum simulation field illustrates this imperative, having evolved from a niche research area to mainstream particle physics community within just a few years. Recent research[54] notes that this is driven by "impressive advancements in Quantum Information Sciences (QIS) and associated technologies." The current quantum industries rely on discoveries from three decades ago, emphasizing that the quantum technologies of 2035 and 2047 depend on the fundamental research we fund today. India needs a broad-based, globally competitive scientific research ecosystem with competent levels of funding and exploratory scientific research, if it aspires to be a leader in quantum science and technologies.

Ease of Doing Science and scaling innovation need significant progress. India has a relatively low share of high quality scientific output, ranking 11th on the 2022 Nature Index that measures scientific output in natural and health sciences, and having publication count that is 6.6% of the US and 8.2% of China.[55] In the Global Innovation Index (GII)[56] – combines both Innovation Inputs and Innovation Outputs, India ranks 39th as per the 2024 GII rankings; India however is one of the top overperformers relative to the level of development.[57] However, there is opportunity to make the innovation environment much better to enable rapid and scaled translation of new technologies like quantum to outputs that impact the economy.

[52] J. Groenewegen-Lau, A. Hmaidi, "China's long view on quantum tech as the US and EU playing catch-up," Dec. 2024.
[53] https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS
[54] Bauer et al., "Quantum Simulation for High-Energy Physics", PRXQuantum 4, May 2023.
[55] 2022 Nature Index. https://www.nature.com/nature-index/research-leaders/2023/country/all/global.
[56] 2024 Global Innovation Index. https://www.wipo.int/web-publications/global-innovation-index-2024/en/gii-2024-results.html
[57] India has made significant strides by improving its GII rank from 66 to 39 in just 6 years from 2019 to 2024.

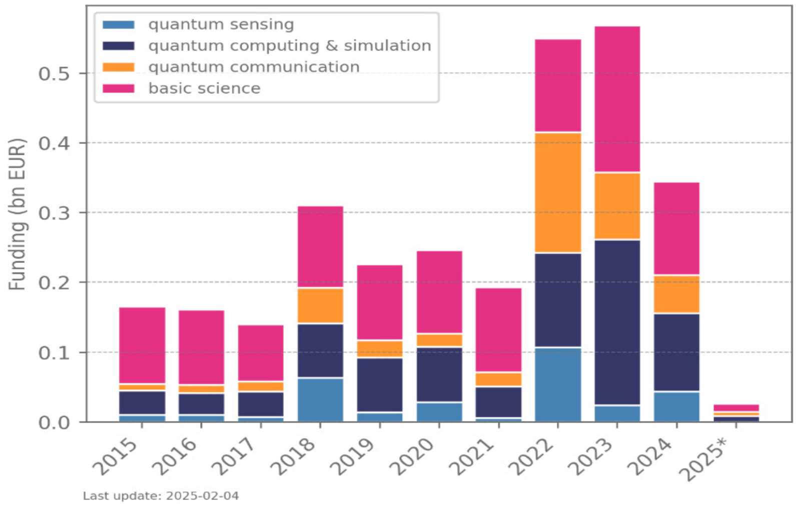


Figure 17: Funding for projects in the EU as per the eGrants database of the European Commission, shows significant funding channeled toward basic science in addition to topical verticals. *Funding data of the 2025 may be incomplete.

The key challenge is that it is not easy to do science in India. The Ease of doing science (EoDS) index is a metric developed by FAST India to measure the ease of conducting science research in a country, which includes factors such as ease of obtaining funds, ease of utilizing funds, developing collaborations, commercialization and institutional support. Researchers surveyed by FAST India gave an average EoDS of 57.6 to the top Indian research institutions, and an average of 80 to foreign institutions where they had experience (Figure 18). Ease of utilising funds was rated lowest, with 58% scientists rating it below average, followed by ease of fundraising and commercialisation with 45-49% rating them below average. The survey found that early career researchers find it harder to utilise funds and getting institutional support compared to experienced researchers, indicating complex processes, people dynamics and lack of documentation. Factors associated with granting agencies were rated as being more difficult than dealing with academic institutes. The factors that received low rating: (i) timelines for processing grants, (ii) availability of big money to conduct research, (iii) objectiveness of selection criteria, (iv) ease of utilisation of funds, (v) funding for international travel and (vi) availability of equipment and resources.

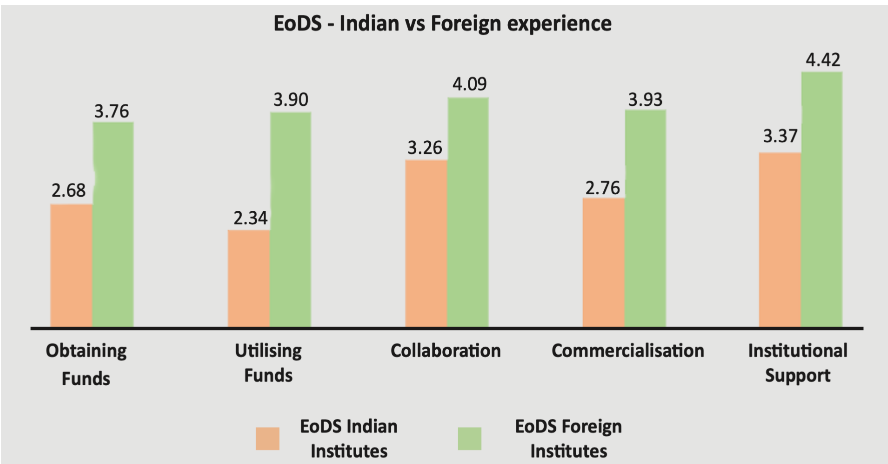


Figure 18: Ease of Doing Science, Indian vs Foreign experience: EoDS in India is 22.4 points below EoDS of Foreign Nations on a 100 point scale. [58]

[58] V. Aggarwal, H. Kaur, K. Misra, and A. Seshadri, Ease of Doing Science Index 2023, Measuring performance of top Indian research institutions, FAST India Report, 2023.

Lack of institutional pathways, incentives and funding for translational research. India needs to address the gap between science and technology that exists today. The gap lies in taking the insights in science and translating it to technology that is needed in the market. This is so because there is additional work needed to translate scientific insights to proof-of-concept (PoC) and then into a minimum viable product (MVP). There is not enough attention paid to funding needed to support this translation research – note that it is still research albeit publishing opportunities may be less, but intellectual property (IP) could be developed. Since academic institutions recognize publications more than IP, and publications are needed for Principal Investigators' (PIs) professional development as well as for student to graduate, taking idea to market is not foremost in the minds of researchers. Academic institutions, and system as a whole, do not recognize value creation towards professional careers of PIs; also, there is a lack of institutional support framework such as longer sabbaticals, managing teaching workload, and freedom to hire professionals on market competitive basis. Further, there are limited grants and challenges – both size and number – that incentivises PIs and students to demonstrate their technology, and to take their idea to market. Government labs, funding agencies and private sector posing technical challenges that can lead to substantive funding, and a promise of adoption, will incentivise researchers to navigate the research to PoC gap with assurance and clarity of purpose.

4.3.4 **Ease of doing business and trade**

(i) Strengths

Early stage military-industrial complex. Traditionally averse to engaging with private sector, Indian defence sector is now changing and is engaging more actively with private sector, more importantly with startups including in deep technologies like quantum.[59] The defence sector in general is seeing a significant growth in recent years which is now forming a kernel of military-industrial complex.[60]

Improving trade relations with other technology centers. In recent times, India has been working with many major countries to improve trade relations and is negotiating possible free-trade agreements with UK, EU, and the US besides others. India is also engaging those countries on more sensitive technologies like defence, nuclear and other strategic technologies.[61]

(ii) Unlocks needed

Process, procurement and audit streamlining and deregulation key for success. India's software success in part is a story of how Indian industry can thrive if provided with an open environment. Indian academia and industry alike that has dependency on engaging with government for procurement of instruments for instance, go through significant challenges. The process is too complex and audit requirements too stringent. It takes a lot of bandwidth and effort to make progress – these are non-tariff barriers that increase cost on industries making them uncompetitive globally. In academia, onus is placed on a researcher to double up as accountant and waste inordinately large amount of time on non-research-oriented work, reducing research efficiency as well as morale. The system largely operates on the presumption of malfeasance.

[59] https://theprint.in/defence/quantum-startup-qubeats-wins-rs-25-crore-govt-grant-to-build-gps-free-navigation-for-indian-navy/2652032/
[60] https://www.theweek.in/theweek/cover/2023/01/14/new-technologies-and-innovations-indian-military.html
[61] https://www.state.gov/u-s-security-cooperation-with-india/

Intellectual property regime and its enforcement needs strengthening. Creation of IP – from application to granting – needs to be done in a time-efficient manner. Enforcement of IP laws needs strengthening as well as dispute resolution needs to be done in a time-bound manner.

Policy uncertainties reduce investor confidence. Deep-tech sector by its very nature has inherent risk of failure, and uncertainties in taxation, process and trade add further to the burden. A responsible taxation regulatory regime, in lines with fiscal responsibility regime, which puts guard rails on taxation will increase investor confidence. A similar uncertainties (arbitrariness) reduction framework in import process and audit requirements would have a very positive effect as well.

Atmanirbharta can have unintended consequences. While being Atmanirbhar is the right goal and aspiration for a country of India's size, sometimes value creation can be stifled due to lack of availability of best technology; this is particularly acute in physical hardware and infrastructure space. It is important to nuance Atmanirbharta against value creation and value chain that is being built on top of the best technology (even if it is not locally available). For sectors where there is skill and capital, and a solution that is emerging, it is best to ensure that they grow rapidly by making the best technology available, and as seamlessly as possible. In due course, market efficiency would create a demand for local sourcing, and over time the talent pool would have evolved into that space as well.

Internationally governments are viewing quantum technologies as strategic assets. Quantum technologies have geostrategic dimensions and many countries such as UK are putting up barriers even for academic collaboration with friendly countries including India. Many countries which are currently technologically more advanced are trying to maintain their lead by treating quantum technologies as strategic assets. Indian government should negotiate with those countries and create spaces for Indian entities – academia and industry – to operate/collaborate.

Standards leadership can be stronger

Standards bodies set norms that a particular sector follows. Once established and adopted, it is hard to change it. India is engaged in such global efforts such as the IEC/ISO joint technical committee via the BIS LITD 38-Quantum Technologies and Applications Sectional Committee, the ITU Focus Group via the TEC National Working Group on Quantum Technology, and other such efforts. While there is involvement from researchers, government and some Indian companies in these global standards efforts, for Indian industry to be competitive globally, there is scope for much deeper and broader involvement especially as the startup sector and enterprise sector in India ramps up development and adoption of quantum technologies. Indian ecosystem should take standards bodies seriously, to participate in it not only to demonstrate involvement but to also take ownership to ensure Indian industries can remain competitive. There are many standards bodies in quantum technologies[62] - like IEC, ISO, JTC – and Indian industry and startup ecosystem should participate and be represented actively in them.

[62] Office of the Principal Scientific Advisor to the Gov. of India, "India's International Technology Engagement Strategy for Quantum Science, Technology and Innovation," 1st ed., Apr 2025. (Refer 1.A.6. Standards)

Important to ensure IP ownership remains in India and create favourable environment for "redomiciling" to India. The last decade has seen an exponential increase in startups in India. There are over 175 unicorns started by Indians but only 67 within the country.[63] There is a process of redomiciling where the startups are incorporating outside India – mostly in the US and Singapore – and operate in India through a subsidiary.

There are multiple reasons why Indian startups redomicile out of India[39]:

- Capital availability relative to other economies like US and Singapore,
- Foreign investments in Indian startups face limitations of capital account convertibility and foreign fund investment caps,
- Policy stifling Indian institutional capital, such as regulatory barriers on insurance,
- Taxation burden higher than other business friendly locations,
- Foreign exchange transactions are challenging due to lack of capital account convertibility, and
- Process and regulatory compliance for merger and acquisitions (M&A) can be steep.

This process – called "flipping" – leads to IP, assets and capital moving overseas to the incorporated country.[64] This means that future fundraising, mergers and/or exits will happen in the host country and not in India. India needs to pay close attention to this as most countries in the world see quantum technologies as strategic, and through "flipping" the IPs will now be owned by entities residing in the host country; this means that the host country can potentially control the flow of technology into India should it serve its interest.

[63] https://law.asia/why-indian-unicorns-choose-offshore-markets/
[64] https://www.financialexpress.com/opinion/onshoring-indian-innovation/2966548/

5. STRATEGIC RECOMMENDATIONS

5.1 Prioritization of Top 3-5 Quantum Opportunity Areas

5.1.1 **Strategic sector.** Given the many ambitious advancements that country is planning for – 5th generation plane, multi-modal communications, theatre commands – it is imperative to adopt advanced technologies like quantum. Quantum technologies can potentially improve solutions to computational fluid dynamics, provide secure communication, provide GPS-free navigation, unearth new materials that can be used in designing better airplanes or submarines and the list goes on. In the competitive global strategic landscape, this sector in particular needs to very open to adopting quantum technologies from the early stage and not wait for it to be mature.

5.1.2 **Health and Pharma.** India is a global player in health and pharma market. There is an opportunity for India to grow from being a cost-effective solution provider of health and leader in generic drugs, to being a leader in health care - leapfrogging to precision medicine, advanced biotech & diagnostics, and a center for novel drug discovery and development. This requires multiple technologies like quantum simulation, sensing and materials to be deployed simultaneously to obtain a fruitful outcome. India is one of few countries that has necessary wherewithal on all the technologies to be able to deliver such an outcome.

5.1.3 **Peripherals.** Peripherals are vital cog that has potentially a large footprint across multiple industry/solution verticals. Cryogenics, advanced sensors, cryo-CMOS, filters, isolators, attenuators, control electronics, high-density wiring, quantum-limited amplifiers, precision machining, optics and opto-mechanics are some of the examples where India can manufacture and sell it to the world. With the geostrategic trend of friendshoring, and India's drive towards Atmanirbharata, there is a window of opportunity that India should avail. These devices are key components in global supply-chain not just for quantum technologies and but for the broader deep technology economy, and offer a larger market to support businesses while quantum applications gradually mature. India needs to have a strong presence in this field to meet the aspiration of being a leader in quantum technologies.

5.1.4 **Logistics.** Gati-Shakti program is national megaproject that is primarily related to logistics as is India's aspiration to be a global maritime player. As India becomes a manufacturing major, including in semiconductors, managing supply chain logistics will be very important for the success of the sector. Quantum technologies like advanced sensors in IoTs, quantum optimization can provide next generation solution and can provide a significant value add in this space.

5.1.5 **Financial services and fintech.** There is a large opportunity to grow in fintech esp. when Indian market cap increases in the coming decades. As Indian economy expands, it will become one of the important markets for global finance. Innovation in both financial instruments and investor base expansion and outreach will be important. On the defensive side, technical challenges like cybersecurity, fraud detection, anomaly detection will become more pronounced. Quantum computing, communications and quantum-safe provide novel way to solve these problems and add significant value to the sector.

5.2 Policy and Investment Strategies

5.2.1 Grow the scientific, deep engineering and professional workforce in deployment by an order of magnitude by 2027-28.

Developing and scaling technology from lab to market needs co-deployment of scientists and researchers, with deep tech and advanced hardware engineers and business-aware professionals working together. While we have many graduates in the sciences and associated areas, today there is a scarcity of a workforce with cutting-edge and globally top-notch experience, in India. Multiple interventions and initiatives may be needed to accelerate the availability, deployment and career viability of such skills. This can include:

(i) Higher remuneration for such skills across academia, technology incubation centres and startups to be competitive with other career alternatives and international opportunities.

(ii) Professional development programs that link business and technology skills in quantum for creating a workforce that can create and grow quantum related businesses. Additionally, dedicated interdisciplinary quantum engineering programs at undergraduate and doctoral, alongside vocational training.

(iii) Development of supporting hardware engineering and technology leadership skills – including global training fellowships that fund and enable training in the best labs globally for deployment back in India.

(iv) Target 120,000 deployed professionals by 2040, with skills spanning multiple disciplines such as quantum physics, material science, optical engineering, quantum information science, quantum-aware business professionals across sales, marketing and business development.

<u>Impacting Visions: V1, V2, V3, V4, V5</u>

5.2.2 Significantly increase industry awareness of the potential of quantum technology for different industries and catalyze much higher investment into quantum technologies by 2027-30.

Quantum technologies will translate to impact at the scale envisioned in our 2035 vision only if there are adopter industries in India that both adopt the technologies and invest into their development. Today there is very little awareness in different sectors and companies of the potential that quantum technologies hold for their business and for their competitiveness; and limited knowledge on the technological advancements made in these technologies, and how close they are to unlock market value. This results in lack of engagement and funding from large enterprises to shape and apply the research and development happening in labs and startups. Multiple interventions will be needed to address this, including but not limited to:

(i) Regular and meaningful knowledge sharing and use case mapping between the developers of quantum technologies (startups and research labs) and the potential adopters (enterprises and public sector entities).

(ii) Joint development, validation and commercialization constructs between the developers and adopters that allow for use case and value aligned technology development while also allowing the adopters to participate in the economic benefit of technology commercialization.

(iii) Facilitate and encourage advancement and deployment of quantum algorithms for application domains to drive economic value and global leadership, while strategic hardware and scientific development is also encouraged separately and in parallel.

(iv) By 2035 reach within top 3 countries with global patents related to quantum technologies.

(v) The government can lead by example and encourage large public sector entities including defence, Indian Railways, oil and gas majors, nationalized banks, power utilities, mining corporations, ports, and Navratna PSUs to adopt quantum computing to address complex, high-impact problems that require computing capabilities that go beyond the capabilities of today's classical computers. This push must happen at a pace faster than the computerisation drive in government and public sector departments during the 1990s.

(vi) Interventions can be deployed to encourage medium-sized industry involved, for example, dedicated government-industry challenge grants, tax incentives for quantum integration, or sandbox programs for sectors such as logistics, materials, or banking

Impacting Visions: V3, V4

5.2.3 Improve ease of doing research, technology validation and lab-to-market significantly by 2027.

To reach our 2035 vision, speed in new scientific research, technology development, scaling and adoption will be critical. The Indian research ecosystem as it stands today, with low ease of doing science index and global innovation index, will need significant help and improvement to enable this. This will need to include interventions on multiple fronts, including:

(i) Much faster deployment of government funds for research and more flexibility in utilization of the funds in terms of timing. Procurement of complex equipment and execution of complex experiments often do not progress with short predictable timelines. It becomes critical to ensure availability of approved funding as and when needed to remove any friction in speed resulting from funding constraints.

(ii) Significantly reduce encumbrances in procurement processes, especially for small to medium sized procurements.

(iii) Simplify hiring human resource requirements – terms and process – and empower people to take decisions related to role definition and renumeration considering prevailing project requirements and market conditions.

(iv) Create new structures for close collaboration and sharing of labs and technologies between government labs, research groups, startups and industry. It may often be the case that a research group develops some new research idea and technology, but the test bed and equipment ready to validate and refine it may exist in some government lab within strategic sectors or with industry. We should set up constructs that allow easy sharing and collaboration across these entities for such technology validation and refinement. This can be in the form of "yellow zones" and "green zones" in strategic sector labs which allow for academic groups and startups to come in and validate and refine their technology. Colocation of university and industry labs, federated testbeds, and periodic open calls for collaborative R&D could enhance impact.

(v) Policies can be deployed to accelerate go-to-market and scaling of products and services, around intellectual property licensing, startup incubation, and early regulatory approvals, especially in healthcare and digital infrastructure. In addition, targeted "innovation incentives" for faculty, streamlined technology transfer offices, and recognition of patent/ IP generation in academic promotion policies.

Impacting Visions: V1, V2, V3, V4

5.2.4 Take steps to substantially grow quality and quantity of fundamental scientific research, while also growing risk appetite in our funding entities and research institutions by 2027-30.

(i) The overall quality and quantity of fundamental scientific research in India needs to grow to reach within the top 10 countries of the world on measures such as R&D funding as percentage of GDP and percentage of publications in top publication venues. India should aim to grow R&D funding, including for exploratory scientific research in areas allied to quantum technologies to at least double of what it is today in terms of percentage of GDP by 2030.

(ii) Our funding entities and our research institutions often tend to embody a low-risk mindset. This creates an environment that can make it challenging for ambitious and independent-minded researchers to step outside the comfort zone and develop atypical and innovative initiatives, and to confidently take up risky projects. In fact, there are many researchers in India who are willing to take risk and be ambitious, but the institutional environment, career drivers, and recognition incentives do not always encourage and support such risk-taking behavior, and do not allow for failures. It is critical for us to change this and make our research institutions and funding agencies become comfortable with failure and risk, to encourage researchers who are willing to be "wild ducks" and reward leadership behaviors, risk-taking, ambition and collaboration with industry, startups and other entities in the ecosystem.

Impacting Visions: V1, V5

5.2.5 Make Indian domicile attractive for Indian startups so that >90% deep tech Indian startups choose to stay domiciled in India.

Because of the trend of "flipping" to offshore domicile, India suffers from loss of intellectual property and assets associated with these startups and unicorns, with 109 Indian founded unicorns choosing to domicile outside India and only 67 in India. Especially in quantum technologies, if India has to be a leader in intellectual property and technology creation, it becomes critical for us to change the environment for startups so that they find it attractive to stay domiciled in India. This will require address multiple areas:

(i) Lower and simpler taxation so that India is more attractive from a tax perspective. Today India stands at a disadvantage with higher tax burden on companies such as higher rates, difficult to avoid double taxation, etc.

(ii) Simplified corporate regulatory framework that allows more flexibility to startups and lowers regulatory burden, in areas such as incorporation, mergers and acquisitions, and fast-track IP registration.

(iii) Easier movement of international funds so make international transactions smoother.

(iv) Incentives for keeping and repatriating domicile and IP to India.

Impacting Visions: V1, V4

5.2.6 Engage actively with global standards bodies and take leadership in international standard setting related to quantum technologies to ensure that Indian products have access to global markets.

It will be critical to ensure that the right experts from India, especially from the industry and the startup ecosystem, are present in these global standards conversations. It is to be noted that playing an active role in global standards to ensure that they are sensitive to our industries will be vital for future economic success.

Impacting Visions: V1, V2, V4

5.2.7 Ensure strong trade relations and ease of technology export and import.

The development and scaling of quantum technologies will depend heavily on ready access to input materials and components from different nations. Similarly, India will need access to global markets for exporting materials, components and products with low trade barriers. Given increasing sensitivity for technology sovereignty in many nations, it will be critical for India to sustain and grow strong trade ties in all areas related to the supply chain and value chain of quantum technologies across materials, components, systems, hardware, software and services. It will be important to have a national quantum supply chain resilience plan, with incentives for local manufacturing of critical inputs and partnerships with trusted international suppliers.

Impacting Visions: V1, V2, V4

6. CONCLUSION

India has a real and present opportunity to develop a strong quantum ecosystem in the country, with both national impact and global leadership, as discussed in this report with the Vision for 2035. For capturing this opportunity and realizing this Vision, India must act on the recommendations in the prior chapter, and overcome the barriers in accelerated development and adoption of quantum technologies.

6.1 Potential Cost of Inaction

Failure to invest in quantum technologies could have profound and far-reaching consequences for India's ambition to become a developed nation by 2047. As quantum stands poised to be one of the most disruptive forces of the century, neglecting it would amplify India's strategic vulnerabilities—forcing reliance on foreign technologies in critical sectors like defence, cybersecurity, surveillance, and advanced communications, while competitors like China continue to rapidly advance their quantum capabilities. Economically, India risks missing out on a sector projected to be worth hundreds of billions to trillions of dollars, which would stifle domestic growth, limit job creation, and potentially turn its demographic dividend into a liability, as millions of working-age individuals could remain underemployed or jobless. This technological lag would also widen the balance of trade deficit, diminish India's market share in high-value global industries, and undermine its competitiveness in manufacturing, semiconductors, and software services. Import dependence on quantum solutions would increase costs and hobble Indian industry, making the transition to a high-income country even more challenging as per capita income lags behind global leaders like China and the US. Ultimately, a lack of robust quantum capabilities would not only endanger national security and critical infrastructure but also erode India's strategic autonomy, as technological dependence could be leveraged by adversaries and even allies to constrain India's options on the world stage.

6.2 Conclusion

This roadmap aims to provide an outlook for what quantum economy would be like in 2035 and what should India do now to be a leading player in quantum economy. The roadmap deconstructs this goal into a set of 5 visions that India needs to set for itself, analysed and identified the critical gaps, and provided 7 actionable recommendations to overcome the gaps. It is hoped that these recommendations will complement and strengthen the NQM's objectives. It will be critical to ensure that the milestones set by NQM, around hardware technologies are achieved as planned.

If the recommendations are adopted, the path from 2035 to 2047 will then be much clearer, where India can capitalize on the strong foundation it builds until 2035 to truly accelerate the path to Viksit Bharat in 2047, and India will be amongst developed nations of that time. This will need India to have the ability to cross-leverage its capabilities and global leadership in quantum to impact other areas of development that will be in focus during the 2035-2047 period. The entire economy and policy landscape should be able to have ready access to the applications and advantage provided by quantum technologies in 2035 and beyond. This is within reach but will need all sections of the ecosystem to rise to this call to action – across policy makers, industry, academia, private capital and the public sector.

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