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Quantum Computing: From Scientific Progress to Shareholder Returns

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See the end pages of this presentation for analyst certification and important disclosures.

Framing The Investment: A Large Opportunity with an Uncertain Route to Cash Flow

$40B
listed pure-play market cap on ~$290M of 2025 revenue (~140x)

6
new listings in 2026 (QNT, IQMX, PSQL, INFQ, XNDU, HQ)

6 teams
in DARPA QBI Stage C (7 Oct 2026): Atom, Diraq, IBM, IonQ, Microsoft, PsiQuantum

$2.0B
US Commerce CHIPS equity stakes in nine firms (May 2026): government as shareholder

What to take away from today

1. **A new accelerator category**: strongest on problems with quantum structure (molecules, materials); not a general replacement for classical compute.
2. **The debate has moved to reliable computation**: useful logical operations at a stated accuracy, cost and time, not headline qubit counts.
3. **Progress is measurable** (below-threshold error correction, logical circuits); economic generalization is premature.
4. **Listed exposure is broader and less homogeneous**: hardware, sensing, foundry and security now share one "quantum" peer group.

Three clocks run at different speeds

Science
Lower errors, reliable gates, useful algorithms

Commercialization
Qualification, installation, utilization, repeat purchase, margin

Equity markets
Liquidity, narratives, financing terms, discount rates: priced generations ahead

How the Industry Got Here: Four Decades of Theory and Lab Physics, Then Engineering

Period	Milestone	Why investors should care	Status
1981–2015	Feynman and Deutsch frame quantum simulation; Shor's algorithm (1994); first error-correcting codes; first NMR, ion and superconducting qubits; D-Wave annealers (2011)	The surviving algorithms date from here; proofs of principle at trivial scale	Settled
2016–2023	IBM puts 5 qubits on the cloud (2016); Google Sycamore "supremacy" (2019); IBM 127-qubit "utility" (2023)	Cloud access defines the business model; each claim drew a classical rebuttal within 1–3 years	Claims disputed
Dec 2024	Google Willow: surface code below threshold (Λ = 2.14 on 105 qubits)	First proof that error correction scales as theory predicts; ignites the retail rally	Settled
2025	Helios 99.921% fidelity, 48 corrected logical qubits; Quantum Echoes 13,000x (Oct); IBM dates Starling for 2029; DARPA Stage B (11 teams)	Records and dated roadmaps; $12.6B of start-up investment; stocks peak in October, then fall 57–78%	Settled; Majorana 1 disputed
2026 to date	Six listings; IonQ buys SkyWater ($1.8B); Commerce takes equity in nine firms; IBM/UChicago 70-logical-qubit claim (Jul); DARPA Stage C (Oct)	The public-market year: audited revenue arrives, with dilution and four macro-driven drawdowns	In progress

Quantum Computing Without the Mystique: An Algorithm Shapes Probabilities Until a Useful Answer Is Measurable

Qubit
A two-level system described by two amplitudes. Measurement returns a classical 0 or 1, never “all possibilities”.

Superposition
n qubits need 2^n amplitudes to describe classically. That makes simulation hard; it is not proof of speedup.

Interference
Amplitudes reinforce or cancel. Algorithms choreograph gates so that wrong paths cancel.

Entanglement
Joint states that cannot be factored qubit by qubit: the resource, and it must be demonstrated.

Measurement
A run yields samples; useful answers need many “shots”. Sampling cost belongs in every comparison.

What the computer actually looks like: the QPU is one subsystem

QPU (qubits) → **Control electronics and readout** → **Cryogenics, lasers, vacuum** → **Classical compute and decoding** → **Compiler, runtime, software**

Investor translation: customers pay for reliable answers, not qubits. The qubit chip is a smaller part of the bill: refrigeration, wiring, control electronics and classical computing cost more, and the gap widens as machines scale. That supporting hardware is where semiconductor companies are exposed.

Where the Speedups Come From: Complexity Theory Is Not a Revenue Forecast

Algorithm / approach	Potential use	Speedup	Investor interpretation
Shor / phase estimation	Factoring, discrete logarithms; properties of quantum systems	Exponential; credible	Needs long, protected computations: RSA-2048 under 1m noisy qubits (Gidney, May 2025)
Hamiltonian simulation	Dynamics of molecules and materials: catalysts, batteries	Exponential; credible	The natural match (“small data, big compute”); ground-state chemistry less settled than dynamics
Amplitude estimation	Monte Carlo pricing, risk and probability estimation	Quadratic	$O(1/\varepsilon)$ vs $O(1/\varepsilon^2)$ on paper; data loading and error-correction overhead decide the crossover
Grover / amplification	Unstructured search, selected subroutines	Quadratic	Hoefler, Häner and Troyer (2023): quadratic speedups are “insufficient for practical advantage”
VQE / QAOA / annealing / quantum ML	Hybrid chemistry, optimisation, logistics, learning on classical data	Heuristic; none proven	Value must be shown problem by problem; dequantisation and strong classical solvers unbeaten at scale

What this does to the TAM: the use cases consistent with the physics consensus are chemistry and materials simulation on early fault-tolerant machines, plus cryptanalysis and the defensive migration it triggers. Discount TAMs built on generic optimisation, logistics, finance Monte Carlo and quantum ML accordingly.

Sources: Hoefler, Häner, Troyer, CACM 2023; Gidney, arXiv:2505.15917; Google Research, Mar 2026 (ECDLP-256 under 500k physical qubits); Quanta (Tang, 2025); Bain Technology Report 2025.

Error Correction Amplifies Economics: Useful Logical Operations, Not Raw Qubits, Measure Progress

Why another "nine" matters so much

Probability that all 1,000 independent operations succeed



For 10,000 operations: 0.0045% and 36.8%. Useful algorithms need errors near one in a billion, so information is encoded redundantly. Willow (Dec 2024) showed logical error halving each time the code grew (Λ = 2.14): the first "below threshold" result.

The requirement is falling faster than hardware grows

Estimated physical qubits to factor RSA-2048 (0.1% gate error assumed)

20M	<1M	<100k
2019, Gidney–Ekerå	May 2025, Gidney	Feb 2026, simulation only

Today's largest gate-model machines hold 98–156 qubits at 99.1–99.92% two-qubit fidelity: three to four orders of magnitude short on count, 3–10x on error rate. Gidney sees no further 10x cut "without changing assumptions".

Six questions to ask about any "logical qubit" claim

Code distance?	Corrected or detected?	Encoding ratio?	Post-selection rate?	Real-time decoding?	T gates and depth?

Sources: Google Willow (Nature, Dec 2024); Gidney, arXiv:2505.15917; Iceberg Quantum via The Quantum Insider (Mar 2026); Quantinuum Helios (Nov 2025).

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The Competing Hardware Approaches: Every Architecture Has an Advantage and a Bottleneck

Approach (leaders)	Best demonstrated, dated	Strength	Main scaling challenge
Superconducting (IBM, Google, Rigetti, IQM, USTC)	Willow Λ = 2.14 (Dec 2024); Nighthawk 120q (Nov 2025); Rigetti 108q at 99.1% (Apr 2026)	Fastest gates; only below-threshold results; 300 mm fabrication	Cryogenic wiring and I/O density; crosstalk; sub-μs decoding
Trapped ions (Quantinuum, IonQ, AQT)	Helios 98 ions, 99.921% two-qubit, 48 corrected logical; IonQ 99.99% claim	Fidelity records; all-to-all connectivity; mature cloud business	Gates 100–1,000× slower; transport dephasing; 2D traps unproven
Neutral atoms (QuEra, Atom Computing, Pasqal, Infleqtion)	3,000 atoms run continuously (Sep 2025); QuEra 96 logical on 448 atoms (Jan 2026)	Scale and reconfigurable codes; no cryogenics	Atom loss and reload; ~1 ms cycles; nobody yet at 99.9%
Photonic (PsiQuantum, Xanadu, Quandela)	Xanadu Aurora: 12 GKP logical qubits; PsiQuantum publishes no Omega metrics	CMOS photonics manufacturing; natural networking	Photon loss; resource-state overhead; timelines slipping to ~2030
Silicon spin (Diraq, Quantum Motion, Intel, Quobly)	Diraq CZ ~99.5%; Intel Tunnel Falls 12q on 300 mm; Diraq in DARPA Stage C	CMOS density and manufacturability; DARPA's densest bet	Tiny qubit counts; variability; pre-logical-qubit
Topological (Microsoft)	Majorana 1 (Feb 2025), Majorana 2 (Jun 2026): single device, no two-qubit gates	Intrinsic protection if real; >1m qubits per chip envisaged	Contested evidence (Nature critique, Jun 2026); 2029 target without data

The Next Technology Milestones: Roadmaps Cluster on 2027–2029, with Definitions That Differ

Company	Delivered (as of Oct 2026)	2026–2027 targets	2028–2029 targets	End state
IBM	Nighthawk 120q and Loon qLDPC couplers (Nov 2025)	Kookaburra module (2026, not yet announced); Cockatoo (2027)	Starling 2029: 200 logical qubits, 10^8 gates	Blue Jay, 2033+
Google	Willow below threshold (Dec 2024); Quantum Echoes (Oct 2025)	Next: a long-lived logical qubit (~10^{-6})	Commercial applications “by 2029” (press)	No dated end state
Quantinuum	Helios 98 ions, 48 corrected logical (Nov 2025)	Sol, 2H 2027 (2D traps in validation)	Apollo 2029: universal fault-tolerant	Lumos after Apollo
IonQ	Tempo 100q (2025); Superion 256 announced (Sep 2026)	Superion 256 deliveries; 10k-qubit chip (2027)	20k qubits on two chips (2028)	2030: 2m physical, 40–80k logical
QuEra / Atom	96 logical on 448 atoms (Jan 2026); 24 logical (Nov 2024)	Magne 50 logical, Denmark (early 2027, from 2026)	Libra 2028: 256 logical, megaquop, on Braket	Gigaquop, >1,000 logical
PsiQuantum / Xanadu	Omega chipset (no metrics); Aurora 12 GKP logical	Brisbane build not started	Xanadu FT operations (2028); PsiQuantum Chicago (2028)	Brisbane ~2030 (from 2027)
Microsoft	Majorana 1 (Feb 2025); Majorana 2 (Jun 2026), contested	Create and entangle 50 logical qubits	Utility-scale 2029, pulled in from 2033	>1m qubits on one chip

Sources: Company roadmaps and press releases

Has Quantum Advantage Arrived? More Relevant Claims, but the Scope Matters Most

The evidence ladder

1 · Physical milestone: device or memory works as specified

2 · Computational advantage: a defined task beats classical

3 · Application advantage: better outcome on a relevant use case (contested)

4 · Economic advantage: value exceeds full cost (unproven)

5 · Profitable platform: recurring demand, sustainable cash (unproven)

Three examples to discuss accurately

Google Quantum Echoes, 13,000x (Nature, 22 Oct 2025)
Verifiable advantage on a physics observable, with a proof-of-principle NMR tie-in; unchallenged after a year. Capability in a defined problem family, not general superiority.

IBM / University of Chicago, 70 logical qubits (30 Jul 2026)
Materials simulation on logical circuits with 468 logical T gates; circuits released for open classical challenge. A scientific claim, not a profitability claim.

HSBC / IBM bond-trading trial, "34%" improvement (Sep 2025)
A prediction-quality improvement versus the study's classical baseline, not profit or a speedup. A cautionary example.

Use cases ranked by evidence quality

PQC migration	Government, HPC	Physics simulation	Chemistry	Finance	Optimisation	Quantum ML
revenue now	revenue now	demonstrated	pre-commercial	claims disputed	theoretical	very low evidence

The Investable Landscape: Eleven Listed Quantum Companies Worth ~$40B

Ticker	Company (modality)	Market cap	FY2025 revenue	FY2026 guidance	Cash (30 Jun unless noted)
IONQ	IonQ (trapped ion + foundry, networking)	$13.4B	$130.0	$450–460M incl. SkyWater	$2.96B (~$4B pro forma)
QNT	Quantinuum (trapped ion)	$9.6B	$30.9M	$28–32M	$2.11B
QBTS	D-Wave (annealing + gate model)	$4.4B	$24.6M	None	$546M
RGTI	Rigetti (superconducting)	$3.9B	$7.1M	None	$541M, no debt
INFQ	Infleqtion (neutral atom + sensing)	$1.9B	$31.1M	~$45M (revised)	$582M
IQMX	IQM (superconducting, Finland)	$1.8B*	€37M	€42–47M target	€309M (2 Jul)
QUBT	Quantum Computing Inc (photonics, foundry)	$1.4B	$0.7M	None	$1.32B
PSQL	Pasqal (neutral atom, France)	$1.2B	€16.5M	None	~€313M (27 Aug)
XNDU	Xanadu (photonic)	$0.9B	$4.6M	None	$313M
HQ	Horizon Quantum (software)	$0.7B	~$0	None	~$120M (Mar)
ARQQ	Arqit (quantum-safe encryption)	$0.2B	$0.5M	None	n/a

Sources: Company filings, Bloomberg Finance L.P.

Size the Opportunity Without Mixing Definitions: Three Numbers That Must Not Be Added Together

Three layers that get conflated

Vendor revenue: what listed companies can book

~$1B (2025) → $4–4.4B (2028–30)

2035: $5–15B (Bain) vs $43–71B (McKinsey); the spread is a bet on fault tolerance by 2029–2033

All quantum technology: computing, communications, sensing

$60–100B by 2035

McKinsey 2026; communications alone $10.5–14.9B, ~45% of it PQC and interconnects

End-user economic value: not revenue for anyone

$1.3–2.7T by 2035

McKinsey 2026; BCG: $450–850B by 2040. Never apply a headline TAM to a market cap

For a semiconductor investor

Company	Disclosed quantum exposure
GlobalFoundries	Dedicated unit; $375M CHIPS award; PsiQuantum, Quantinuum, Diraq, Google as customers
IBM	Anderon 300 mm quantum foundry, $1B CHIPS + $1B IBM; >$10B five-year pledge
Nvidia	NVQLink across 17+ QPU builders; stakes in Quantinuum, PsiQuantum, QuEra; under 1% of revenue
Keysight, FormFactor	Control electronics and cryogenic probers (export-controlled); peers Qblox, Zurich Instruments, Bluefors are private
AMAT, LRCX, KLAC, ASML, TSMC	No quantum revenue disclosed: exposure below 1%
Oxford Instruments	Exited: NanoScience cryogenics sold to Quantum Design (Jan 2026)

Sources: McKinsey QTM 2025/2026; Bain 2025; BCG (Jul 2024); company releases

Post-Quantum Cryptography: The Spending That Does Not Wait for the Hardware

1 Jan 2027
NSA CNSA 2.0: new national-security acquisitions and firmware signing must be quantum-resistant

2030 / 2035
NIST deprecates RSA-2048 and ECC P-256, then disallows them; EU high-risk systems by end-2030

~70%
of browser traffic to Cloudflare already uses hybrid post-quantum key exchange (Sep 2026)

0 of 24
major US federal agencies fully meet GAO's three PQC preparation practices (Oct 2026)

Why buyers pay before a capable machine exists

- **Harvest now, decrypt later:** data with a long shelf life (state, health, financial, IP) can be stored today and read once the hardware arrives
- **Migration takes years:** inventories, PKI and HSM swaps, firmware and long-lived devices; the deadlines are fixed even though Q-Day is not
- **The standards are final:** ML-KEM, ML-DSA and SLH-DSA (FIPS 203–205, Aug 2024); HQC chosen as a backup (Mar 2025)
- **The target keeps getting closer:** qubits to break RSA-2048 fell from ~20M (2019) to under 1M (2025), the estimate on slide 6

Who captures the spend: mostly classical security and silicon

Layer	Disclosed facts
Secure silicon	Infineon: first Common Criteria (EAL6) certification of a PQC algorithm on a security controller (Jan 2025)
FPGA and IP	Lattice MachXO5-NX TDQ, first PQC-ready FPGA family (Oct 2025); Rambus Quantum Safe IP
Network and cloud	Cloudflare, Cisco, Palo Alto, Thales; hybrid ML-KEM already the browser default
Qubit makers	Little direct exposure: quantum key distribution and networking add-ons

Sources: NSA CNSA 2.0; NIST FIPS 203–205, IR 8547; EU NIS Cooperation Group roadmap (Jun 2025); GAO-27-108740 (Oct 2026); Cloudflare (29 Sep 2026); Gidney (May 2025); Infineon (Jan 2025); Lattice (Oct 2025).

Valuation and Risks: Time, Funding and Dilution Decide Shareholder Outcomes

Reverse the valuation (illustrative: 8x revenue exit in year 5, 20% hurdle)

Enterprise value today	Required year-5 revenue	At 50% probability of success
$5B	$1.56B	$3.11B
$10B	$3.11B	$6.22B
$20B	$6.22B	$12.44B

Delay is expensive: present value of the same $10B exit at 20%

Exit in year 5	Exit in year 7	Exit in year 8
$4.02B	**$2.79B**	**$2.33B**

A three-year delay removes ~42% of present value before any extra development spending; the same $10B equity outcome is $100 a share on 100M shares and $50 on 200M.

How dilution works across the group

- **Follow-ons and at-the-market sales:** raises tend to follow rallies, when issuing is cheapest
- **Warrants:** SPAC-era and newly attached warrants add shares as the price rises; their liabilities swing GAAP results with the stock
- **Stock-funded M&A:** acquisitions paid in shares lift revenue faster than revenue per share
- **What to check:** fully diluted share count, cash runway in quarters, organic versus acquired revenue per diluted share

The principal ways the thesis can fail

Risk	What to monitor
Logical scaling fails	Logical error vs code size; correlated noise; repeated-cycle results
Classical competition	Open benchmarks; every supremacy claim so far was matched within 1–3 years

Sources: Company filings; Bloomberg Finance L.P.

Milestones and Discussion: An Unusually Dense Run of Verifiable Checkpoints

Timing	What to watch, and why it matters
Q4 2026	Q3 prints (IonQ's first quarter with SkyWater; Quantinuum's path to $28–32M); IBM Kookaburra; Elisity close; remaining Commerce LOIs
1 Jan 2027	NSA CNSA 2.0: new acquisitions and firmware signing must be quantum-resistant; the nearest hard PQC catalyst
2027	Quantinuum Sol (2H); IBM Cockatoo; Magne live in Denmark; IonQ Superion 256 deliveries; German €640m competition; EU Quantum Act
2027–2028	DARPA QBI Stage C findings: the independent verdict on whether any utility-scale design survives scrutiny
2028	QuEra Libra (256 logical) on Braket; IonQ 20k-qubit system; DOE Quantum Genesis fault-tolerant target
2029–2030	IBM Starling, Quantinuum Apollo, Microsoft's claim; NIST deprecates RSA-2048 (2030); EU high-risk PQC migration

More bullish if

- An error-corrected useful result survives twelve months unmatched
- Kookaburra and Sol land on time; Stage C validates a design
- Repeat customers and organic gross profit improve with scale

More cautious if

- Integration milestones slip; growth comes mainly from acquisitions
- Stage C quietly stops promoting teams; metrics grow vaguer

"The most attractive opportunities turn measurable technical progress into repeatable customer value enough economics for shareholders. The next few years should show which companies can make tha

Sources: Company roadmaps; DARPA; NSA CNSA 2.0; NIST IR 8547; EU NIS Cooperation Group roadmap (

