INVESTING IN PERPETUAL FIVE-YEAR TECHNOLOGIES (PFYTs)

Quantonation Whitepaper — 2025 Edition

CHRISTOPHE JURCZAK
MANAGING PARTNER

NOVEMBER 2025

QUANTONATION

INVESTING IN PERPETUAL FIVE-YEAR TECHNOLOGIES (PFYTs)

SUMMARY

This white paper introduces the concept of *Perpetual Five-Year Technologies* (PFYTs) — scientific and industrial domains that remain "five years away" because their scaling depends on the alignment of physics, engineering, and policy ecosystems. Drawing on examples from the portfolio of the venture capital firm Quantonation, it argues that patience, discipline, and active ecosystem building can turn long-horizon science into an investable reality. PFYTs already exist: SpaceX and Figure AI exemplify technologies that once seemed perpetually distant but have now redefined their industries; NVIDIA, though not itself a PFYT, shows how patient mastery of hardware can catalyze them — and many more lie on the horizon, especially across the physics-based domains central to Quantonation's scope. This white paper lays out the vision and future direction of the fund as it expands from quantum technologies to the broader class of PFYTs shaping the next industrial frontier.

Panel at the Alain Aspect Symposium 2024 – Photo © Agence Oblique / Quantonation

THESE PERPETUAL FIVE-YEAR TECHNOLOGIES (PFYTs) ARE NOT FAILURES. THEY ARE FERTILE GROUND FOR PATIENT, DISCIPLINED, AND STRATEGICALLY STRUCTURED INVESTMENT

Quantonation sits at the intersection of deep science and venture capital. Our mission has always been to identify technologies that are not incremental but transformative — those that shift the scientific and industrial landscape itself. Yet, time and again, we encounter the paradox of technologies described as being "five years away."

This phrase — sometimes dismissive, sometimes aspirational — captures a structural reality. Quantum computing, nuclear fusion, directed energy, compact particle accelerators, and other fields have cycled for decades between promise and delay. They gather attention and funding, only to see timelines slip further.

At first glance, this looks discouraging. But seen differently, it is a guidepost for venture capital. These Perpetual Five-Year Technologies (PFYTs) are not failures. They are fertile ground for patient, disciplined, and strategically structured investment. In a world that has spent the last two decades compounding returns on bits, PFYTs bring venture back to atoms — to the physical frontiers where breakthroughs depend on matter, energy, and scale, not just computation.

At Quantonation, we see the PFYT framework as a natural extension of our thesis — a way to evaluate opportunities, guide portfolio construction, and shape the Ecosystem Building approach we are pursuing. Over the years, I've come to think of PFYTs as a lens for understanding not just markets but time itself — how physics teaches venture patience.

We began with quantum technologies: the physics frontier most clearly embodying that ambition. From this foundation, we have expanded into adjacent physics-based domains — extreme-light systems, quantum materials— where the same deep-science logic applies. This evolution reflects a conviction: that the class of PFYTs forms a new category of investable assets.

Quantum technologies, once considered speculative, are now recognized as a strategic asset class. The sector exceeds $50 billion in public market capitalization, with total ecosystem value — across public, private, and corporate holdings — approaching soon one trillion dollars.

At Quantonation, PFYT also evokes the deep-physics territories where strategic positioning and active ecosystem building can finally transform "five years away" into investable reality and impact. This underlines the importance of these elements in successful investment strategies.

Christophe Jurczak
Managing Partner
@ Quantonation Ventures

PFYTs THAT HAVE CROSSED THE THRESHOLD

PFYTs are not theoretical. Several technologies once mocked as perpetually "five years away" have now become foundational to modern industry.

The history of artificial intelligence captures the PFYT dynamic in miniature. In the 1950s, pioneers such as Marvin Minsky imagined machines that could learn, reason, and perceive — ambitions that would spend half a century oscillating between excitement and disappointment. For decades, neural networks remained an elegant idea in search of enough data and the right hardware substrate. Then, in the early 2010s, the pieces finally aligned: abundant data, parallel computation, and new architectures turned deep learning from a research curiosity into the engine of digital intelligence across language, science, and materials.

At the center of this transition stood NVIDIA — not itself a PFYT, but a company whose sustained commitment to physical-layer performance made many PFYTs possible. By transforming the GPU from a gaming component into the computational substrate of modern AI, NVIDIA turned a niche hardware business into the enabler of a new computing paradigm. Its success was not the outcome of a fixed master plan but of disciplined conviction in the long-term potential of its architecture. When the neural-network breakthroughs arrived, NVIDIA was already equipped with the tools to unleash them — a reminder that patient investment in enabling hardware can redefine entire frontiers. Such revolutions are rarely linear; progress accumulates quietly, through thousands of refinements that eventually reach critical mass.

SpaceX broke through a half-century of stagnation in space launch economics. Reusable rockets turned a "five-years-away" ambition into operational routine, demonstrating that long-horizon physics can yield venture-scale outcomes through vertical integration and milestone-driven design. Their rapid build-test-learn cycles, though costly, generated data that accelerated learning — a hallmark of successful PFYT execution.

Photo © SpaceX

PFYTs CROSS THRESHOLDS NOT GRADUALLY BUT SUDDENLY—WHEN THE RIGHT COMBINATION OF COMPUTATION, CAPITAL, AND COORDINATION ALIGNS.

A similar pattern is emerging in robotics. For decades, humanoid robots capable of meaningful real-world work were perennially on the horizon. Today, thanks to breakthroughs in AI and control systems, companies like Figure AI are showing machines that can perform structured tasks — the first glimpse of ubiquitous robotics, the mature expression of “AI meets the physical world”. The importance of this cannot be underestimated. AI will only become truly impactful (and profitable) once it starts interacting on large scales with the real world. As Yann LeCun has argued, the path toward general intelligence may itself require such large-scale interaction with the real world.[1]

Virtual and augmented reality are crossing their own threshold. Once bulky lab prototypes, AR/VR systems are now compact, networked, and powered by machine vision and generative interfaces. They mark the broader shift from digital immersion to physical interaction, a frontier between computation and perception.

Autonomous vehicles embody another PFYT arc: extraordinary complexity, slow public rollout, but steady deep learning, sensor fusion, and regulatory advances that cumulatively make self-driving systems an inevitable reality rather than an ever-postponed dream.

Across all these cases, the pattern is the same: patient and well-dimensioned capital, a focused early market, and the acceleration of the discovery–deployment loop through intelligence and iteration. PFYTs cross thresholds not gradually but suddenly—when the right combination of computation, capital, and coordination aligns. To borrow — and slightly misuse — Hemingway’s famous line, technologies scale “two ways, slowly and then all at once.” For PFYTs, that is precisely the point: long plateaus of learning followed by sudden leaps. The trick is to be invested before the plot twist.

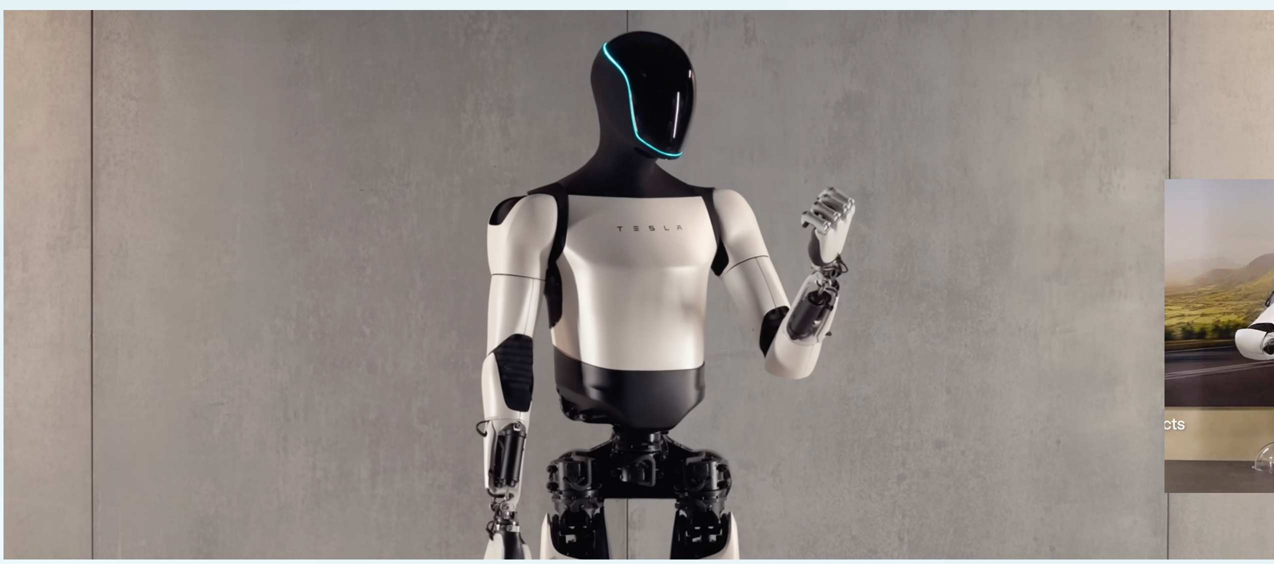


Photo © Tesla, Inc.

[1]Jason Howell: “Meta AI Chief Yann LeCun: Human Intelligence is not General Intelligence”, 2025

UNDERSTANDING THE PFYT PHENOMENON

From our vantage point as investors working at the frontier of physics, one lesson repeats itself: physics is unforgiving. Scaling from proof of concept to commercial deployment requires not only scientific breakthroughs but also robust supply chains, testing and qualification infrastructure, and regulatory maturity. Unlike office or web software, which can scale by code alone, each step toward scale depends on building entirely new layers of physical capability. Neutral-atom quantum computers, for instance, demand precision laser systems, photonic integrated circuits, and ultra-high-vacuum chambers — each an enabling technology that creates value on its own.

These systems are inherently nonlinear: small improvements or instabilities can lead to disproportionate outcomes. This nonlinearity allows for extraordinary gains in performance or efficiency, but it also makes precision engineering and reproducibility far more demanding than in purely digital domains.

Even when timelines slip, progress is substantial: each phase solves key bottlenecks, reveals hidden constraints, and filters dead ends. That process of elimination and refinement is what makes long development cycles so valuable. As the story of Haber and Bosch in *The Alchemy of Air*[2] reminds us, turning sound physics into scalable industry can itself be a form of discovery. The engineering challenges — sometimes as mundane as how to stop pressure vessels from cracking — often determine success as much as the underlying science. Scaling, in this sense, is its own kind of invention.

This dynamic is evident across many PFYTs. In quantum computing, for example, some of the hardest hurdles — from qubit coherence to large-scale system integration — have already been cleared, yet new ones continue to appear. Often, the real obstacles only become visible once earlier ones are solved. The discovery of qubit leakage as a critical factor in error correction, for instance, reshaped entire roadmaps. Such recursive learning is typical of deep-physics technologies: each step forward exposes a deeper layer of complexity, prompting new cycles of adaptation that refine both the science and the business models around it.

SCALING FROM PROOF OF CONCEPT TO COMMERCIAL DEPLOYMENT REQUIRES NOT ONLY SCIENTIFIC BREAKTHROUGHS BUT ALSO ROBUST SUPPLY CHAINS, TESTING AND QUALIFICATION INFRASTRUCTURE, AND REGULATORY MATURITY.

[2] Thomas Hager: The Alchemy of Air: A Jewish Genius, a Doomed Tycoon, and the Scientific Discovery That Fed the World but Fueled the Rise of Hitler, 2008.

In quantum computing, even the definition of “the computer” remains fluid. Beyond the dominant digital paradigm, a diversity of models — analog, digital-analog, continuous-variable, and multi-valued — are emerging, each exploiting the very specific and rich information encoding capacities brought by quantum physics through distinct abstraction layers. Rather than converging on a single architecture, the field is unfolding into a taxonomy of purpose-built machines, from analog simulators to hybrid processors. This plurality captures the essence of PFYTs: technologies that evolve faster than any fixed roadmap can describe. The evolution of quantum computing exemplifies how PFYTs mature: progress redefines not only performance metrics but the very language used to describe them.

Pasqal Ruby processor installed at CEA TGCC HPC center (France) Photo © Pasqal

The delays are systemic, not accidental. Amara’s law[3] reminds us that we consistently overestimate the impact of new technologies in the short term while underestimating them in the long term, as illustrated by Masayoshi Son, who once held about 5% of Nvidia before selling it, a stake that would be worth over $250 billion today. This explains why PFYTs can be hyped to excess, disappoint investors in the near term, yet eventually reshape industries once enabling conditions fall into place. Similarly, the Collingridge dilemma[4] shows that in the early stages of a technology, we lack the knowledge to steer its development effectively, but by the time it matures, path dependencies make change difficult. Together, these frameworks explain why PFYTs appear forever on the horizon and why, once they finally cross the threshold, they transform sectors almost overnight. From the outside, such a change seems sudden; from within, it is the cumulative result of years of iteration, learning, and disciplined engineering.

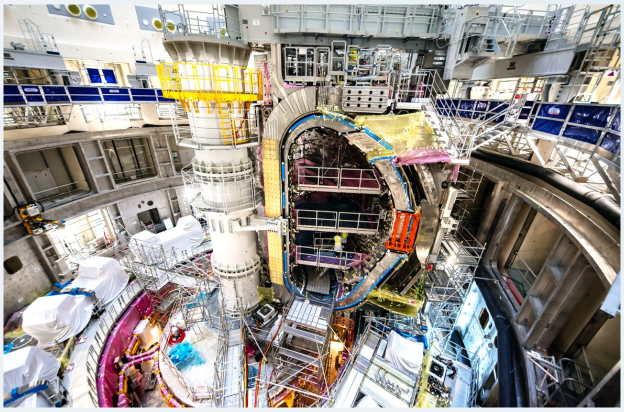
[3] Pohan Lin: Amara’s Law and Its Place in the Future of Tech, Mar. 2024
[4]David Collingridge: The Social Control of Technology, 1980.

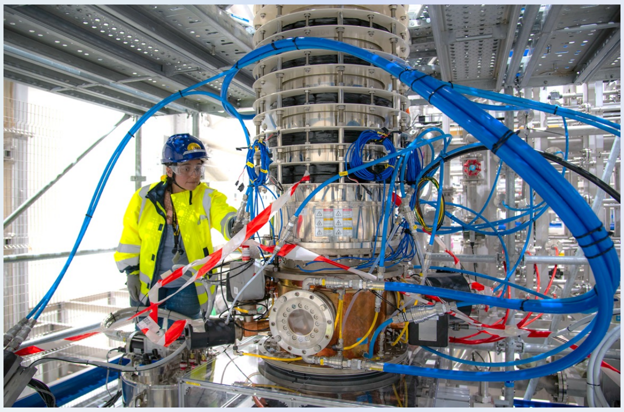
Amara's law also resonates with the concept of *temporal discounting* in behavioral economics and neuroscience, the human tendency to overvalue immediate rewards while undervaluing distant ones, even when the latter are objectively larger. This bias contributes to chronic underinvestment in long-horizon technologies, from climate to fusion to quantum, and helps explain why PFYTs often remain underfunded despite their potential. Yet paradoxically, committing higher up-front investment — though riskier — often accelerates progress, reduces exposure to competition, and ultimately lowers the risk of a project "dying on the vine."

Crucially, PFYTs are strategic bets, not blind gambles. They are bets on physics and computation that may take decades to mature, but unlike a gamble, they deliver value along the way. Every few years, progress is real, measurable, and often monetizable: quantum processors already run algorithms with quantum advantage in niche markets and train a workforce, even if industrial use cases are still limited; molecular simulation improves drug pipelines even if whole-cell models remain aspirational; laser-powered accelerators enable compact, high-flux radiation sources already used in space-radiation testing. Each milestone opens a partial market, sometimes worth billions, while building toward an even larger endgame.

PFYTs differ fundamentally from the well-known *Industry X.0* paradigm. While Industry 4.0 and its variants focus on digitizing and optimizing existing processes, PFYTs redefine what is physically possible. They create new materials, machines, and energy systems — not merely smarter versions of existing ones. Quantonation invests in invention curves, not adoption curves —a distinction that guides our strategy.

PFYTs overlap with what is often called *Deep Tech* or *Hard Tech*, but they are not synonyms. Deep Tech describes technologies grounded in scientific and engineering depth; PFYTs describe a temporal and systemic condition. They are the technologies that remain "five years away" because their scaling depends on the alignment of scientific, industrial, and policy ecosystems. Not all deep technologies are PFYTs: semiconductor manufacturing, for instance, advances through mature industrial playbooks, whereas PFYTs progress through compounding breakthroughs that continually reshape their enabling stack. In short, Deep Tech speaks to what a technology is; PFYTs speak to how it *evolves*. The two intersect, but PFYTs add a theory of time, coordination, and investment patience to the Deep-Tech vocabulary.





Construction and assembly of the tokamak reactor core
Photo© ITER Organization

Development and assembly of photonic quantum processors (Quandela) - Photo © Agence Oblique / Quantonation

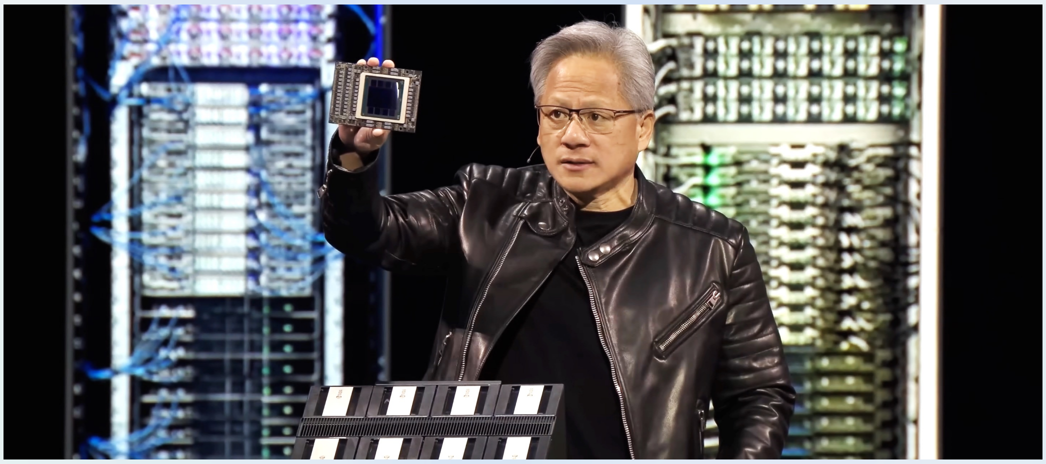
A defining feature of PFYTs is this *technological interdependence* : progress in one field often depends on breakthroughs in another. Advances in cryogenics enable new qubit architectures; laser systems matured for fusion unlock next-generation photonics; and materials research in superconductivity feeds back—sometimes serendipitously—into energy and computation. Each layer of progress reveals new constraints, making integration across disciplines not optional but necessary. This recursive interdependence explains the vertical integration of ventures like SpaceX, where propulsion, software, and manufacturing co-evolve, and the full-stack architectures of quantum computing firms, which must master hardware, control electronics, and algorithms as a single system, at least for a time in their development. In PFYTs, learning propagates through the stack: every solved obstacle exposes a deeper one.

That same logic, long evident in the co-design of hardware and software and in the co-evolution of hardware and materials, is now moving into intelligence itself — giving rise to systems where learning acts directly on matter.

IN PFYTs, LEARNING PROPAGATES THROUGH THE STACK: EVERY SOLVED OBSTACLE EXPOSES A DEEPER ONE.

PHYSICAL AI: THE COMPRESSION LAYER

Across the PFYT landscape, intelligence, whether embodied in AI models, adaptive control, or digital twins, has become inseparable from physical engineering. Two complementary movements are at work. First, AI accelerates discovery in the physical world, for example, using machine learning to identify new materials for plasma confinement, superconductivity, or catalysis. Second, we are witnessing the emergence of new physical embodiments of intelligence itself, where information theory in the Shannon sense finds expression on novel substrates, from quantum processing units on various substrates to photonic quantum-safe communications.



Jensen Huang at GTC Paris 2025 © Nvidia Corporation

This convergence between intelligence and physics is not new: The very foundations of neural networks, inspired by physical models of energy minimization, go back to John Hopfield's work in the early 1980s, recognized by the 2025 Nobel Prize in Physics. His models illustrated that learning and physics share a common language of equilibrium and constraint satisfaction, a lineage that today resurfaces in physical AI systems linking computation and material dynamics.

This continuity between physical theory and embodied intelligence now extends from abstract models to full-scale engineering practice, where feedback, optimization, and control merge across hardware and software. SpaceX's flight software and iterative design loops are as data-driven as its rockets are mechanical. NVIDIA's AI systems turned hardware into learning machines. Robotics represents their fusion: intelligence directly acting on matter.

Across these examples runs a common thread: the convergence of intelligence and matter into a single process of becoming. Physical AI marks a new stage in this evolution, the point where learning systems engage directly with the material world, allowing information and physical processes to coevolve. In this sense, AI is no longer just a tool for analysis, but a participant in the formation of the technical object itself. Yet, every act of intelligence requires contact with reality: data do not preexist but arise through interaction when instruments, sensors, and algorithms mediate between knowledge and matter.

EACH ADVANCE IN PHYSICAL TECHNOLOGY OPENS A NEW DOMAIN OF DATA, AND WITH IT, NEW DIMENSIONS OF INTELLIGENCE.

Physics remains our most powerful means of generating such contact, of turning the unknown into measurable form. Each advance in physical technology opens a new domain of data, and with it, new dimensions of intelligence. The fusion of physics and AI is therefore not a simple coupling of disciplines but a dynamic co-evolution — a process through which intelligence and the physical world individuate together, often on timescales far longer than market cycles permit.

In this light, the Physical-AI paradigm is less a technical framework than a mode of technogenesis. It redefines invention itself: AI no longer accelerates discovery from the outside, but operates within the material process, guiding it toward stability and function. In fields once constrained by slow, empirical iteration, intelligence now learns from the systems it shapes — discovering catalysts, superconductors, and alloys; refining optical and plasma systems through predictive feedback; co-designing mechanical and electronic architectures as adaptive ensembles. Physical AI thus compresses the cycle of experimentation and invention, reducing uncertainty while preserving the open-ended character of creation. It signals a new stage in the evolution of technology — one where the frontier between discovering and fabricating, between knowing and becoming, grows increasingly porous.

The effect is profound: PFYTs, long defined by slow feedback loops between theory and experiment, can now advance at the pace of computation. Physical AI does not eliminate the hard physics — it compresses it. It is therefore both *an enabler of PFYTs* and, increasingly, *a PFYT of its own* : the new frontier where digital intelligence directly shapes the material world.

Laser-plasma accelerator - Photo © Tau Systems

FUNDING PFYTs: A VENTURE MODEL

The venture capital model thrives on asymmetry. The rare bets that succeed return the entire fund (the *Power Law*), and PFYTs are ideally suited for this model because their eventual successes are not marginal, but transformational. Reusable rockets, once mocked as "always five years away," have become routine and fundamentally altered satellite launch economics.

At Quantonation, we have seen firsthand how many brilliant PFYTs suffer from chronic underfunding in the *Valley of Death* — the gap between proof-of-concept and commercial scale. This creates an opportunity for contrarian capital to step in where others hesitate. Moreover, the enabling technologies that PFYTs depend on - detectors, cryogenics, photonic components, advanced materials, and sophisticated control systems — are often commercially valuable in their own right. Investing in these "picks and shovels" allows us to capture value regardless of how quickly the prime technology reaches maturity: these enablers often have shorter paths to commercial revenue and exit, providing the potential for earlier returns while our larger bets mature.

For PFYTs, the role of venture capital cannot be merely to "map, bet, and be patient". These are not passive investments. Success requires active accompaniment: shaping consortia, co-developing industrial partnerships, engaging public agencies, and helping founders navigate complex financing architectures that combine equity, grants, and project capital. Patience, however, must be paired with discipline. Clear benchmarks are essential, not only to reassure investors, but also to ensure that teams are making sound technical and strategic decisions at every stage.

Being "five years away" cannot become an excuse for drift; measurable progress is what distinguishes persistence from inertia. In practice, this means coupling conviction with discipline and humility before physics - setting milestones that respect the pace of engineering reality rather than the expectations of financial cycles. This is especially critical when scaling involves public–private interfaces, complex M&A, or transitioning founding teams earlier than in traditional software ventures.

Signing of EIF's investment as a Limited Partner in Quantonation II
Photo © Agence Oblique / Quantonation

Yet, this should not be seen as a tension between capital and founders but as a chance to redefine how they collaborate. Many PFYT founders are driven not only by financial ambition but also by the desire to see a lifelong scientific vision realized, a motivation deeply tied to personal agency and creative independence. In academic and scientific contexts, especially, high performers are motivated by mastery and purpose once basic financial security is achieved. Recognizing this human dimension calls for investment models that align institutional capital with the intrinsic motivations of founders - enabling them to innovate at the edge of the possible, while ensuring that the structures around them sustain continuity, growth, and renewal.

Founders must also learn to take pride in the so-called “boring” challenges of scaling — the painstaking problem-solving where breakthroughs for industrialization truly happen. As Elon Musk has noted, scaling is often harder than invention itself; embracing that reality is key to transforming scientific prototypes into enduring industries. We have seen it repeatedly across our portfolio: progress that looks incremental day to day but becomes transformational in retrospect.

Yet the challenge is not only motivational but cognitive. In many PFYT domains, the physics is sound, but the engineering is hard: founders trained as scientists must learn to think as systems architects. Programs such as DARPA’s Quantum Benchmark Initiative are beginning to encourage this shift — helping teams ask, early on, “What will this look like at scale?” and fostering the systems-level mindset needed to turn breakthroughs into industries.

PFYTs progress through thresholds — proof-of-concept, demonstrator, pilot, and scale — rather than linear increments. Quantonation structures its investments accordingly — blending venture equity with strategic co-investments, public programs, and project finance. Adequate stage-gated funding at each inflection point, early customer engagement, and internationalization are core principles of the PFYT playbook — ensuring progress is never constrained by being “built on the cheap.”

Photonic Quantum Computer development - Photo © ORCA Computing

IN THE PFYT WORLD, FOUNDERS ARE NOT JUST SEEKING CAPITAL; THEY ARE PARTNERING WITH INVESTORS WHO CAN HELP ORCHESTRATE ECOSYSTEMS AND PUBLIC–PRIVATE BRIDGES.

PFYTs are shaped as much by policy as by science. Quantum technologies have become strategic instruments, attracting more than $50 billion in global public R&D. Similar dynamics extend to fusion ($2.6 billion in the 12 months before July 2025) among other sectors. Public-private initiatives, from DARPA and ARPA-E to the EU and US Chips Act and national quantum missions, are critical accelerants. Quantonation's involvement with these programs provides unique visibility into emerging PFYT opportunities.

Beyond capital shortages, PFYTs face structural frictions: regulatory uncertainty, entrenched incumbents resistant to disruption, and high switching costs or network effects that slow adoption. These forces often require a blend of patient capital and active engagement — working with policymakers as mentioned above, corporates, and standards bodies — to unlock markets rather than waiting for them to mature organically.

This active stance also redefines the relationship between founders and investors. In the PFYT world, founders are not just seeking capital; they are partnering with investors who can help orchestrate ecosystems and public–private bridges. This inversion — from the era when funds competed to attract founders, to one where PFYT founders seek the few investors capable of scaling deep-science companies — is a defining feature of the coming decade.

This combination of transformational potential, underfunding, and investable enablers makes PFYTs a natural hunting ground for Quantonation. To move from theory to practice, however, we must map the terrain clearly.

PHYSICS-BASED PFYTs: THE LANDSCAPE

Many PFYTs arise from hard-physics bottlenecks, but the framework applies to long-horizon domains such as self-driving cars, AI, synthetic biology or climate engineering. Here we focus on the *physics-based* class—where the constraints are material, energetic, or quantum, not biological or algorithmic.

These are technologies that have lived for decades in cycles of promise and delay, where the physics is sound but the engineering and ecosystem challenges push deployment further out. What unites them is the repeated refrain of being “five years away” — yet each incremental breakthrough opens valuable markets and strengthens the case for long-term transformation.

Quantum control hardware testing (Qblox)
Photo © Agence Oblique / Quantonation

As highlighted in a recent *Le Monde* op-ed I wrote with colleagues[5], progress in these domains depends on the complementarity between public research and entrepreneurial execution. Fundamental laboratories provide the long-horizon exploration of materials, architectures, and measurement techniques that feed future startups, while startups, in turn, reveal new scientific challenges through the constraints of manufacturability, integration, and performance. Structuring this relationship as a continuum—through shared infrastructure, open collaborations, and aligned incentives—helps keep PFYTs from stalling once the first prototypes appear, ensuring that discovery and industrialization advance together.

In computation, PFYTs range from quantum processors and the quantum internet to alternative and probabilistic paradigms. Within quantum computing itself, progress is unfolding across multiple encoding and compute modalities rather than converging on a single design. Each reflects a different balance between universality, control, and resource efficiency. This diversity is not fragmentation but maturation: a sign that quantum computing is evolving from a singular vision into an ecosystem of specialized architectures.

[5] Antoine Browaeys et al.: En physique quantique, la complémentarité entre start-up et laboratoires est vitale, Le Monde, Sept. 2025

As the mathematician Karl Sigmund observed in *The Waltz of Reason* [6], "one can conceive machines more powerful than our digital computers, having for instance a continuous set of states." Yet, as he noted, mathematical self-discipline historically confined computing to discrete, digital logic. The return of analog and hybrid paradigms — in both quantum and AI hardware — can be read as a reopening of that older question: what forms of computation nature itself might permit, and how far we can push the boundaries of physical learning.

In energy, PFYTs include nuclear fusion, advanced fission reactors, and space-based solar power — each constrained by long development timelines yet surrounded by a growing ecosystem of enabling technologies. From high-temperature superconductors (tentatively) and advanced plasma control to precision laser systems, novel fuels, and radiation-resistant materials, these innovations are building the foundations for the next generation of clean-energy systems. While full deployment may remain decades away, partial markets are already emerging — in materials, diagnostics, and control systems — demonstrating that progress in energy PFYTs accumulates well before commercial scale is reached.

Brain-Computer Interface - Photo © Adobe Stock

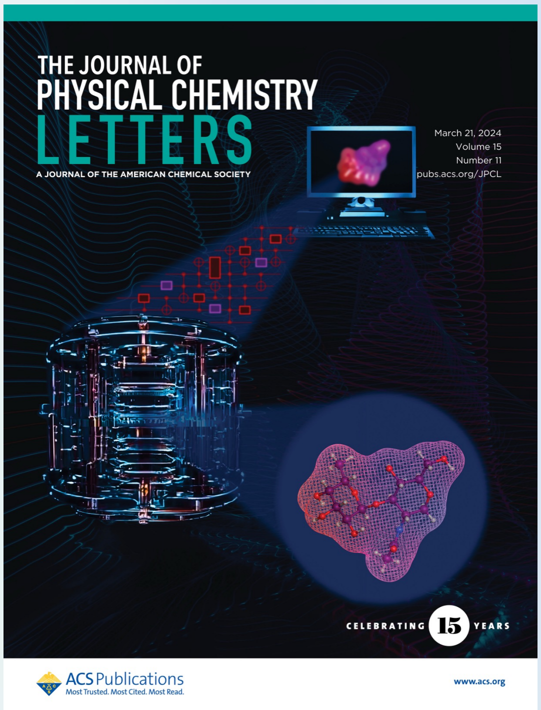
In sensing and measurement, PFYTs include quantum inertial and gravity navigation, hyperspectral and terahertz sensing, and even compact beam and muon systems, where laser-plasma physics is turning once-fundamental experiments into industrial diagnostic and imaging tools. At the intersection of physics and biology, brain–computer interfaces and neuro-quantum hybrids point to a frontier where sensing, AI, and matter interact directly with cognition.

Each of these technologies opens markets in defense, navigation, healthcare, climate, and fundamental physics, but all face recurring bottlenecks in ruggedness, manufacturability, and scale.

New generations of enabling quantum and functional materials are emerging across nearly every domain. They serve as platform technologies with applications ranging from drug discovery and catalysis to energy storage, conversion, and generation. Their versatility makes them strategically valuable but also difficult to structure within traditional venture frameworks. In parallel, advances in molecular simulation show how even partial progress is already transforming these industries, while the full vision of predictive, atom-level modeling remains decades away.

[6] Karl Sigmund: The Waltz of Reason: The Entanglement of Mathematics and Philosophy, 2023.

Quantum materials development (Pioniq)
Photo © Agence Oblique / Quantonation



Quantum algorithm for chemistry (Qubit Pharmaceuticals)
Photo © The Journal of Physical Chemistry

Taken together, these PFYTs are not science fiction. They are active areas of global R&D, each with vibrant communities, prototypes, and roadmaps. What holds them back is not discovery, but scale-up, manufacturability, and integration, precisely the domains where venture capital and patient company building can play key roles.

Integration is often the hidden frontier. Many deep-physics innovations struggle not because they fail scientifically but because they do not fit easily into existing industrial systems. Whether a material, component, or process can be “dropped in” to current supply chains often determines its economic viability far more than its performance metrics. Helping founders think through this interface — between new physics and inherited infrastructure — is also where venture support can be most catalytic.

TAKEN TOGETHER, THESE PFYTS ARE NOT SCIENCE FICTION. THEY ARE ACTIVE AREAS OF GLOBAL R&D, EACH WITH VIBRANT COMMUNITIES, PROTOTYPES, AND ROADMAPS.

FROM QUANTUM TO THE PHYSICS FRONTIER

The PFYT framework reveals a class of technologies where physics and underdeveloped supply chains impose long timelines — but where value, learning, and markets accumulate incrementally. With venture capital recovering from the glut of SaaS and easy software in the mobile era of the 2010s, we are now seeing progress in real PFYTs from self-driving to AI to Quantum.

In quantum in particular, what was once “five years away” is now an investable sector with mature companies, public listings, and growing customer markets. Throughout its portfolio of 27 companies in the field (and 36 including adjacent technologies), Quantonation has demonstrated how patient venture capital, ecosystem orchestration, and scientific depth can turn a field of promise into a strategic asset class. After a decade watching this evolution from the inside, I have learned that patience is not passive; it is an active stance - a form of engineering in its own right.

The same expertise that enabled success in the quantum sector positions us to identify and tame the next physical frontiers. For Quantonation investors, this strategy offers exposure to the most transformative physical technologies of the coming decades — before they become apparent. Yet beyond capital and engineering, I am convinced that real progress will demand something more: a revival of interdisciplinarity and imagination. Startups often embody this better than research institutions — they bring physicists, chemists, biologists, computer scientists, and designers into the same room, solving problems that no discipline alone could frame in an academic lab. We need that spirit not only to build industries but also to imagine what science itself could become in the very long term.

In my experience, physicists — myself included — often lack that imagination. We are trained to ask what is possible, but not always what it might be for. The frontier ahead will belong to those who can do both. Yet, imagination, to be meaningful, must return to the world, to the places where discovery happens. There is a thrill in walking through a top physics lab and spotting the faint outlines of a company before anyone else sees it. To go lab by lab — from Saclay to Stanford, from Tokyo to Singapore or Sherbrooke — is to rediscover what venture creation once was: curiosity turned into enterprise.

Physics may set the limits of what is possible, but venture defines how fast we can reach them. PFYTs sit at that intersection — where discovery becomes industry, and patience becomes strategy. For those willing to engage deeply with science and stay the course, the perpetual frontier is not a mirage; it is the next market. For me, this conviction comes from experience: seeing how a theory becomes a company, and a prototype becomes an industry. Quantonation’s portfolio offers concrete illustrations of this PFYT dynamic: ventures initially backed for their scientific depth that, in retrospect, embody the framework’s logic of threshold progress and ecosystem co-development (see Table).

TABLE: EXAMPLES OF PFYT STARTUPS IN THE QUANTONATION PORTFOLIO

Company	Year Founded	Core Technology	Key Achievements	Fit with PFYT and Long-Term Vision
Tau Systems	2021	Enabling laser–plasma accelerators that create compact, high-energy particle and X-ray sources — 100× smaller and cheaper than conventional systems.	Prototype operational in Carlsbad (2025); world record 10.4 GeV laser-driven electrons.	A quintessential PFYT translating Nobel-winning laser physics into industrial infrastructure. Bridges physics and manufacturing; aims to democratize access to high-energy photon and particle sources.
Qubit Pharmaceuticals	2021	Quantum–AI simulation platform (FeNNix-Bio, Hyperion orchestrator) unifying chemistry, biology, and materials discovery.	Demonstrated quantum-precision molecular dynamics on HPC; early drug and catalyst candidates	Embodies PFYT's vision of Physical AI: fusing quantum mechanics, computation, and chemistry toward a foundation model of matter.
Pioniq	2023	Solid quantum electrolytes enabling new classes of batteries, supercapacitors, and micro-devices.	Two patent families; 10+ publications; reversible Zn-based microbattery.	PFYT of the energy frontier: emergent quantum states of matter applied to safe, recyclable, and sovereign energy storage. Targets global leadership in post-lithium materials.
Pasqal	2019	Neutral-atom quantum processors enabling both analog and digital fault-tolerant quantum computing, deployable on-prem or in cloud.	Global leader in multimodal quantum computing; 40+ clients; 7 QPUs in production; partnerships with IBM, NVIDIA, Microsoft Azure, and Google Cloud; hybrid applications in finance, energy, and drug discovery.	Foundational PFYT: Pasqal exemplifies the trajectory from lab breakthrough to deployed infrastructure — where quantum computing becomes integral to future HPC and cloud ecosystems. Lessons learnt on engineering for scale with a platform approach and deep attention to supply chain.
Qblox	2018	Modular quantum-control stacks and electronics enabling scalable, low-latency feedback across superconducting, spin, neutral-atom, and photonic qubits.	140+ employees (25% PhDs); 120+ customers worldwide; patented picosecond-sync protocols; leading control processor (Q1 Core); on track for ASIC and cryogenic integration.	Provides the hardware backbone bridging physics and computation — transitioning quantum control from lab setups to data-center-grade infrastructure.

PORTFOLIO COMPANIES QUANTONATION I & II

QUANTUM COMPUTING

- Pasqal
- Quandela
- ORCA Computing
- Nord Quantique
- quobly
- Multiverse Computing
- Qubit Pharmaceuticals
- HQS Quantum Simulations
- KIPU Quantum
- QCDesign
- diraq
- Quantum Signals
- P11
- PrediQT

QUANTUM NETWORKS

- Qunnect
- KETS
- QPHOX
- Welinq
- CryptoNext Security
- memQ
- evolutionQ
- VeriQloud

DEEP PHYSICS

- inSpek
- Sensorium
- SteerLight
- Resolve Stroke
- TAU
- PIONIQ

QUANTUM SENSING

- Qnami
- FOCUS
- EuQlid
- Pixel Photonics

ENABLERS

- QBLOX
- pinc
- ZOO

QI PORTFOLIO

QII PORTFOLIO

EXITED COMPANIES

- Qu & Co
- qb quantum benchmark
- LightOn

THINKING WITH THE TECHNOLOGIES WE BUILD

At a time when technology often advances faster than the philosophical and political reflection that should guide it, I have come to believe that deep-science investors carry a responsibility that goes beyond capital. Our role is to help rebuild the dialogue between science, industry, and thought - to ensure that invention remains connected to meaning.

The French philosopher Gilbert Simondon[7] saw every invention as a process of individuation — a shared becoming of matter, knowledge, and society. More recently, thinkers such as Jürgen Renn[8] and those in the lineage of Bruno Latour[9] have reminded us that technological revolutions transform not only our industries but also our ways of learning and organizing collective progress.

These ideas resonate deeply with what we see every day: that PFYTs are not merely investments but steps in a much longer process of understanding — the way humanity learns to work with the laws of nature. Writing this white paper has been a way to articulate that intuition. It is only a first step, but one grounded in conviction and gratitude for those building the frontier.

[7] Gilbert Simondon: Du mode d'existence des objets techniques, 1958.
[8] Jürgen Renn: The Evolution of Knowledge, 2020.
[9] American Philosophical Association: Remembering Bruno Latour and His Contributions to Philosophy, Oct. 2022

ACKNOWLEDGEMENTS

Photo © Quantonation

This paper has benefited from many conversations with the founders and management teams of the Quantonation portfolio companies whose experience continues to shape our understanding of what it means to build deep-physics ventures. I am grateful to them for their insight and feedback on early drafts. My thanks also go to my partners Olivier Tonneau and Will Zeng, and to the Quantonation team — especially Ylan Tran and Yu-Hsin Wang — for their constant engagement and intellectual generosity.

I owe special thanks to Alvaro Veliz Osorio for his thoughtful reading and very valuable suggestions, including notably the references to Hemingway's "two ways, gradually and then suddenly" and to the story of Haber and Bosch as told in *The Alchemy of Air*.

Any overstatements or errors are mine, but the optimism running through these pages is shared with everyone building the physics frontier.

QUANTONATION — INVESTING IN THE PHYSICS FRONTIER SHAPING THE 21ST CENTURY

QUANTONATION VENTURES
SOCIÉTÉ PAR ACTIONS SIMPLIFIÉES – 135 704€ SHARE CAPITAL
REGISTERED UNDER NUMBER 849 813 522 RCS PARIS
58, RUE D'HAUTEVILLE -75010 PARIS
APPROVED BY THE AMF UNDER NUMBER GP-202211

QUANTONATION