

# PATHFINDERS CAPITAL

## Reading the Frontier

A Pathfinders Capital investment strategy guide to the Emerging Technologies 2025 — Ten technology areas, one cross-cutting framework, and where pre-seed and seed capital should be looking now.

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Pathfinders Capital – The *Lab-to-Term Sheet*® Investor  
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# Letter from Pathfinders Capital: Why We Built This

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Every year, a handful of industry analysts and institutions publish research surveys ambitious enough to be genuinely useful to an early-stage investor rather than just interesting to read. Several policy making organizations such as World Economic Forum (WEF), Hoover Institute, BCG, McKinsey, Booz Allen Hamilton, universities such as Stanford, MIT, University of Michigan, ETH Zurich, engineering publications such as IEEE, SPIE, Nature update latest progress on various Emerging Technologies. But we regularly read them as Pre-Seed and Seed investors.

That distinction matters, and it's the reason this report exists. When various organizations ask: what should the United States know about these technologies to make good policy? We ask a narrower, more selfish question of the same material: what should **Pathfinders Capital** know about these technologies to write good pre-seed and seed checks in Enterprise IT and Deep Tech? The answers frequently diverge from various report's own framing, and that divergence is the point. A government or policymaker cares that biotechnology could add trillions to global GDP. We care that the DNA-synthesis hardware layer underneath that opportunity is underbuilt and investable today. A policymaker worries about nuclear fuel-security dependence on Russia. We see a domestic supply-chain startup thesis.

This report distills ten technology-area briefings — each also published as a standalone piece in our DeepTech Signal web series — into a single reference document, plus one section found nowhere else: a cross-cutting framework built from the patterns that recur across all ten technologies, not just within any one of them. We think that framework, more than any single technology bet, is the most durable thing we can hand a founder or a co-investor.

Three notes on how we used the source material. First, the investment framing, the “where we're looking” calls, and every judgment about what is or isn't a fit for Pathfinders are entirely our own. Second, we analyze overall trends — including the ones in therapeutics, blockchain applications, and clinical neuroscience — but we say plainly where we drew the line around our own mandate. We do not invest in Blockchain and Crypto, Consumer Tech, FinTech, or pure BioTech, Life Sciences, and Pharma without a genuine IT or deep-tech core. Third, this is a framework: we intend to revisit next year and other primary research updates, and as our own diligence — including our active work on adversarial-emulation and exposure-management platforms in cybersecurity — sharpens these theses further.

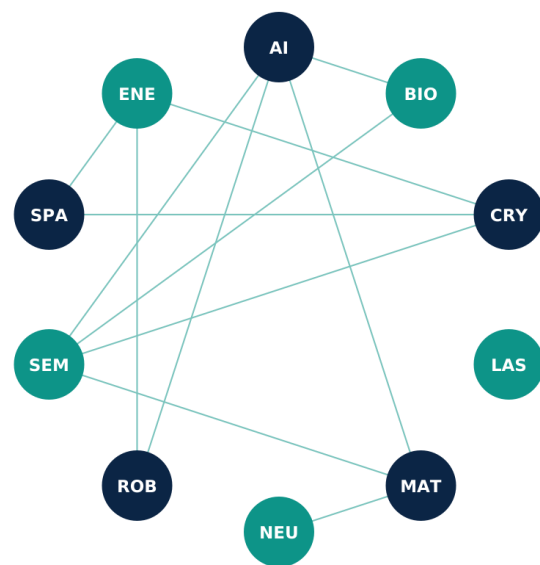
— Pathfinders Capital – The *Lab-to-Term Sheet*® Investor.

# The Cross-Cutting Investment Framework

Many analysts devote quite some time to themes that cut across all technology areas — patterns in how innovation actually happens, independent of which specific field is involved. We found three patterns showed up, in some form, in nearly every report we analyzed for this report. We think they're more useful to a pre-seed and seed investor than any single-sector forecast.

## 1 — Convergence Is the Moat, Not the Sector

We are explicit that none of ten technology areas below develops in isolation — advances in one routinely unlock advances in another, often in directions that aren't obvious from a sector-based view of the market. AI accelerates materials discovery; cheaper semiconductors drove down the cost of DNA sequencing; materials science produces the neural probes that make brain-machine interfaces engineering-feasible; energy technology improves the batteries that both robots and spacecraft depend on. The diagram below sketches some of the convergence pattern we track most closely across our own theses.



*Selected cross-technology dependencies in ten areas. Lines indicate a usage dependency, not an exhaustive map.*

# Two More Patterns Worth Underwriting Against

## 2 — The Valley of Death Is a Recurring Market Inefficiency

We specifically name this gap explicitly in our materials science and sustainable energy segments: a technology can become too mature to qualify for research grants — because the underlying science is no longer in question — while still being too early for venture investors, who hesitate to fund pilot-scale validation that hasn't yet proven a commercial business model. Dedicated mechanisms, such as the Department of Energy's Loan Program Office, exist specifically to plug this gap.



We take this pattern as a standing invitation, not a warning. A fund built for genuine technical diligence — one willing to underwrite a pilot-scale materials or energy company before its business model is fully proven — is exploiting a structural gap that both government and generalist VC systematically under-serve or avoid. This is precisely where we expect Pathfinders' domain depth to outperform capital that can't tell a validated pilot from an unvalidated one.

## 3 — Timing Risk Cuts Both Ways

We frame this as the “Goldilocks challenge”: innovation that arrives too fast can outrun safety, security, and societal acceptance (GMO backlash in Europe and the Concorde's grounding over noise and cost); innovation that arrives too slowly costs a nation — or a company — the first-mover advantage. Durable monopolies on any given technology are becoming harder to sustain as costs fall and diffusion accelerates.

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*Technology often progresses in fits and starts, with long periods of incremental results followed by sudden breakthroughs — the speed of change is hard even for leading researchers to anticipate.*

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For us, this means two things in practice. First, we underwrite founder teams on their ability to move a technology from pilot to product quickly once the breakthrough moment arrives, not just on the elegance of their current roadmap. Second, we treat “first mover in an extremely narrow window” as a more realistic goal for portfolio companies than “durable category monopoly,” and we size our expectations for exit outcomes accordingly.

# Artificial Intelligence

BEYOND THE FOUNDATION MODEL

**THE SIGNAL** — We treat AI as a general-purpose technology on par with electricity and the internet: the value shows up in what it enables elsewhere, not in the model itself. Frontier-model training costs (an estimated tens of thousands of GPUs running for months, on the order of a few hundred million dollars in hardware alone for a model like GPT-4) have closed the foundation-model layer to all but a handful of hyperscalers and frontier labs.

## ~\$10B

Meta's announced 2024 chip purchase, vs. Princeton's \$9M endowment-funded chip buy the same year

## \$42.5B

AI start-up venture funding in 2023, down only 10% amid a 42% drop in overall VC funding

## EU AI Act

In force Aug. 2024; imposes mandatory instrumentation on "high-risk" AI systems

Model capability is also commoditizing quickly. We see durable value migrating toward three adjacent layers: the middleware connecting foundation models to OT (physical domain) and IT systems (embodied AI, agent orchestration); the governance, evaluation, and red-teaming infrastructure that we think regulation is about to make mandatory; and compute-efficiency tooling that lets smaller teams compete efficiently without hyperscaler-like budgets.

### WHERE WE'RE LOOKING

- Embodied-AI middleware: simulation, sim-to-real transfer, and evaluation harnesses bridging model reasoning to physical actuation
- AI governance and evaluation infrastructure: explainability, red-teaming, provenance/watermarking, bias auditing
- Compute-efficiency and SLM orchestration tooling for cost-sensitive enterprise deployment

## Biotechnology & Synthetic Biology

THE INFRASTRUCTURE LAYER UNDER BIOLOGY, NOT THE DRUG

**THE SIGNAL** — We argue biology is heading toward a “personal computer moment” — moving from centralized, capital-intensive biomanufacturing toward distributed production wherever there's sugar and electricity. The clearest near-term evidence is the emergence of bioLLMs — genomic and protein foundation models (Stanford's “Evo”) that generate novel biological sequences rather than merely predicting structure.

**~350 vs. 41**

Top-cited synthetic biology papers, China vs. US, 2023

**\$2–4T**

McKinsey's projected annual economic impact of biotechnology within two decades

**116,000L**

Antheia's fermentation batch size in its 2024 distributed-biomanufacturing demonstration

bioLLMs' real bottleneck isn't model capability — it's wet-lab validation throughput. That bottleneck is the investment thesis: platforms pairing generative bio-design with automated, high-throughput “design-build-test-learn” lab infrastructure are the winners here, not the AI models alone.

### WHERE WE'RE LOOKING

- Enzymatic DNA synthesis hardware — the under-invested counterpart to well-funded DNA sequencing
- Biofoundry automation and lab robotics for design-build-test-learn cycles
- Genomic/protein foundation-model infrastructure: compute, data pipelines, validation tooling
- Early-stage electrobiosynthesis (“eBio”) process engineering

**Out of scope:** Therapeutics, drug discovery, and clinical/healthcare applications fall outside Pathfinders' mandate. But we read all material for platform signal only.

## Cryptography & Post-Quantum Security

HARVEST-NOW-DECRYPT-LATER, NOT BLOCKCHAIN

**THE SIGNAL** — Today's public-key cryptography is secure only because deriving a private key from a public one would take longer than the age of the universe on classical hardware. Quantum computing, once realized at scale, breaks that assumption — and data encrypted today can be captured and stored by adversaries now, to be decrypted retroactively the moment sufficient quantum capability exists.

### May 2022

National Security Memorandum initiating the US quantum-resistant algorithm transition

### Zero-Knowledge

Proofs and secure multi-party computation, already deployed for fraud detection and privacy-preserving analytics

### Multi-year

Typical enterprise timeline to discover and migrate embedded cryptographic dependencies

We treat post-quantum migration as a systems-integration and discovery problem — essentially CTEM applied to cryptographic assets — sequencing algorithm swaps across legacy systems without breaking production. Zero-knowledge proofs and secure computation, meanwhile, are productizable enterprise data-security tools independent of any blockchain use case.

### WHERE WE'RE LOOKING

- Crypto-agility tooling: discovery and inventory of cryptographic dependencies across the enterprise stack
- Post-quantum migration platforms that sequence and validate algorithm swaps without production risk
- Secure-computation and zero-knowledge infrastructure for enterprise compliance and cross-organization data sharing

**Out of scope:** Blockchain applications, cryptocurrency, and central bank digital currencies (CBDCs) fall outside Pathfinders' mandate on Blockchain and Crypto.

## Lasers & Photonics

THE HIDDEN DEPENDENCY ACROSS FOUR OTHER THESES

**THE SIGNAL** — Lasers rarely present as a standalone venture category — they show up as the enabling layer inside semiconductors, defense tech, space tech, and quantum computing. Because laser advances tend to occur inside specific applications rather than a unified research program, real technical differentiation remains available at the component level even in a mature field.

### 10–100x

Laser communication data rates vs. radio, already operational via Starlink's inter-satellite links

### 2.2 MJ

Beam energy at Lawrence Livermore's National Ignition Facility, driving net-energy-gain fusion

### III-V

Semiconductor materials needed for light emission, but they are incompatible with silicon integration

Silicon-photonic integration is best understood as a semiconductor packaging and materials problem, not a lasers problem in isolation. Laser-cooled atoms and ion traps are also a genuine alternative qubit architecture — meaning a strong laser-control team is, in effect, both a lasers company and a quantum-hardware company.

### WHERE WE'RE LOOKING

- Silicon-photonic integration and packaging for AI data-center interconnects
- Beam-pointing, tracking, and thermal management for directed-energy and space-laser-comms platforms
- Laser-based qubit control systems (ion trap, cold atom) for quantum hardware

**THE SIGNAL** — Materials science underlies robotics, space, energy, and synthetic biology, yet we are unusually explicit that materials innovations routinely fall into a funding gap: too mature for research grants, too early for venture capital. Berkeley Lab's autonomous “A-Lab” — synthesizing and characterizing materials in a closed automated loop — achieved 36 full successes and 7 partial ones across 58 targeted materials, though real scientific criticism of its characterization accuracy.

**36 / 58**

A-Lab's full-success rate on targeted autonomous material syntheses

**10x**

Battery capacity increase from silicon-nanowire anodes vs. bulk silicon

**Valley of Death**

term for the pilot-scale funding gap for materials startups

We read the funding gap as confirmation of a market inefficiency, not a reason for caution: a technically fluent fund should be more, not less, comfortable writing pre-seed checks into pilot-stage materials teams. The A-Lab pattern — lab automation and robotics applied to materials discovery — is a horizontal platform thesis, and validation + characterization tooling is a more durable bet than prediction models alone.

**WHERE WE'RE LOOKING**

- Autonomous materials synthesis and characterization platforms (the A-Lab pattern, productized and hardened)
- Pilot-scale materials manufacturing bridging the valley-of-death funding gap
- Validation and characterization tooling for AI-guided materials discovery (batteries, photonic substrates, semiconductor materials)

## Neuroscience & Neurotechnology

SENSING HARDWARE, NOT CLINICAL TREATMENT

**THE SIGNAL** — We open this with a rare investor's admission: public interest in neuroscience vastly outpaces actual scientific understanding of the brain. The most mature brain-machine interface example — Stanford's artificial retina project — succeeds precisely because the retina is an unusually well-characterized, externally controllable neural circuit, not because of any general theory of cognition.

### ~86B

Neurons in the human brain, per various technology reports

### ~1%

Share of neurons in a region that must be sampled to usefully characterize its activity

### Electrode

Long-term implant packaging remains the primary unsolved engineering bottleneck

The durable pattern: winning near-term BCI approaches pick well-characterized, engineering-tractable neural circuits rather than promising general cognitive interfaces. The actual bottleneck is electrode materials and packaging engineering — squarely a materials science and precision-manufacturing problem — plus the data infrastructure needed to capture and interpret high-throughput neural recordings at scale.

### WHERE WE'RE LOOKING

- Implantable electrode materials and packaging for long-term biocompatibility
- High-throughput neural recording instrumentation and real-time signal processing
- AI decoding systems mapping neural activity to device control without full circuit-level understanding

**Out of scope:** Alzheimer's and Parkinson's treatment economics, addiction neuroscience, and depression therapies are therapeutics and clinical applications outside Pathfinders' mandate.

## Robotics & Automation

DEMAND-PULL FROM QUANTIFIED LABOR SHORTAGES

**THE SIGNAL** — We catalog robotics opportunity by labor shortage rather than by technical capability: manufacturing, construction, eldercare, agriculture, and last-mile delivery all face quantified, structural labor gaps that make automation adoption likely regardless of how incrementally the underlying technology improves. Across nearly every application, the unsolved bottleneck is consistently the same: dexterous manipulation, not perception or navigation.

**78%**

Construction firms reporting difficulty filling positions, pre-pandemic

**3–5x**

Faster bricklaying from Construction Robotics' SAM100 vs. a human mason

**>20%**

Share of Americans over 65 by 2030, driving eldercare-robotics demand

Commercial proof points already exist — SAM100 and FBR's Hadrian X in construction — but both still require meaningful human involvement, pointing to where the next wave of value creation sits: closing the remaining manual gaps in already-commercial platforms. Validation and simulation infrastructure for safety-critical robotics is a horizontal opportunity every robotics company in a regulated domain shares.

### WHERE WE'RE LOOKING

- Dexterous manipulation hardware and control systems generalizing across agriculture, logistics, and eldercare
- Construction robotics closing manual gaps in commercial platforms (mortar finishing, brick loading)
- Simulation and validation infrastructure for safety-critical (surgical/telerobotic) robotics

**THE SIGNAL** — The cost-per-transistor curve Moore's law predicted tracked reality closely from 2004–2012, then flattened and hasn't kept pace since. As monolithic scaling loses its economics, the industry is shifting toward chiplets and 2.5D/3D heterogeneous integration. This lowers the capital intensity of competitive chip design: a startup no longer needs to out-fabricate TSMC — it needs a better chiplet or a smarter way of combining them.

**60% / 90%**

TSMC's share of global contract / advanced-node semiconductor manufacturing

**~115,000**

Projected US semiconductor job growth by 2030;  
~58% at risk of going unfilled

**6+ qubit types**

Competing physical approaches to quantum hardware, none with a clear scaling path yet

Photonic interconnects and advanced thermal management are increasingly hard physical constraints on AI infrastructure buildout, not secondary engineering details — a 256-GPU compute pod already dissipates roughly a third of a megawatt. Quantum computing remains a component-level, qubit-modality-agnostic bet, not a category-level one.

**WHERE WE'RE LOOKING**

- Chiplet and heterogeneous-integration design tooling lowering the capital intensity of chip design
- Silicon-photonic packaging and integration for AI data-center interconnects
- Advanced thermal management for high-density compute clusters; qubit-modality-agnostic quantum hardware tooling

**THE SIGNAL** — For the first time since Sputnik, space is dominated by private investment and private actors rather than superpower governments — a \$630B global space economy in 2023 forecast to reach \$1.8T by 2035. The more useful story for seed-stage diligence is orbital congestion: active satellites grew roughly tenfold from 2014 to 2024, with no traffic-management infrastructure comparable to terrestrial transportation systems.

**~10,000**

Active satellites in 2024, up from ~1,000 in 2014

**2 companies**

Astroscale and Northrop Grumman — the only firms with demonstrated in-orbit servicing capability

**\$70B**

All-time-high private space investment, 2021–22

Space situational awareness (SSA) is fundamentally a sensing, data-fusion, and analytics business with satellites as its sensor layer. In-space servicing, assembly, and manufacturing (ISAM) has a remarkably short list of proven players, and NASA's Starling mission demonstrates a genuinely software-heavy opportunity: vision-based, GPS-independent autonomous navigation for smallsat constellations.

**WHERE WE'RE LOOKING**

- Space situational awareness platforms combining satellite sensing with data fusion and analytics
- In-space servicing, assembly, and manufacturing (ISAM) startups building rendezvous-and-proximity capability
- Vision-based, GPS-independent autonomous navigation software for distributed smallsat constellations

# Sustainable Energy Technologies

THE SHARED PHYSICAL CONSTRAINT UNDER EVERY OTHER THESIS

**THE SIGNAL** — US electricity demand could grow up to 100% relative to 2022 levels, driven explicitly by AI data centers, EV electrification, reshored manufacturing, and green-technology policy. Long-duration storage is structurally unsolved by lithium-ion: storing just 72 hours of world electricity consumption would require roughly 240 terawatt-hours of battery capacity — more than a billion tons of batteries at current density.

## Up to 100%

Projected US electricity demand growth vs. 2022, driven substantially by AI

## 240 TWh

Battery capacity needed for 72-hour global storage — ~86x 2023's production capacity

## 10–15 yrs

Even optimistic private investors' timeline to commercial-scale fusion power

Nuclear's investment case is now a supply-chain and manufacturing story more than a physics one — fuel-security dependence on Russia for enriched uranium is a domestic-supply-chain startup thesis in its own right. Grid modernization is the most software-native, capital-efficient entry point in the entire sustainable-energy landscape.

### WHERE WE'RE LOOKING

- Sodium-ion and alternative-chemistry batteries for long-duration and grid-scale storage
- Domestic HALEU fuel supply chain and specialized nuclear-manufacturing capability
- Grid modernization software: demand management, vehicle-to-grid platforms, “energy AI”

# The Ten Technologies at a Glance

A single reference matrix synthesizing where we see the investable layer, the primary risk, and the stage fit for pre-seed and seed capital across all ten 2025 emerging technology areas.

| #  | AREA                    | INVESTABLE LAYER                                                       | PRIMARY RISK                             | STAGE FIT     | SCOPE NOTE      |
|----|-------------------------|------------------------------------------------------------------------|------------------------------------------|---------------|-----------------|
| 01 | Artificial Intelligence | Embodied-AI middleware; governance/eval tooling; compute-efficiency    | Model capability commoditizing fast      | Seed          | Full scope      |
| 02 | Biotech & SynBio        | DNA synthesis hardware; biofoundry automation; bioLLM infrastructure   | Wet-lab validation throughput bottleneck | Seed          | Ex-therapeutics |
| 03 | Cryptography            | Crypto-agility & PQC migration tooling; ZK/secure computation          | Enterprise migration cycles are slow     | Seed          | Ex-blockchain   |
| 04 | Lasers & Photonics      | Photonic packaging; beam control; laser-based qubit control            | Materials integration (III-V/silicon)    | Pre-seed/Seed | Full scope      |
| 05 | Materials Science       | Autonomous synthesis/characterization; validation tooling              | Valley-of-death pilot funding gap        | Pre-seed      | Full scope      |
| 06 | Neuroscience            | Implantable electrode materials; neural recording infrastructure       | Long-term biocompatibility unsolved      | Seed          | Ex-clinical     |
| 07 | Robotics                | Dexterous manipulation; construction robotics; sim/validation infra    | Manipulation dexterity still unsolved    | Seed          | Full scope      |
| 08 | Semiconductors          | Chiplet design tooling; photonic packaging; thermal management         | Capital intensity at fabrication scale   | Seed          | Full scope      |
| 09 | Space Technology        | SSA data fusion; ISAM/RPOD; GPS-independent smallsat navigation        | Long sales cycles, high capex            | Seed          | Full scope      |
| 10 | Sustainable Energy      | Alt-chemistry storage; HALEU supply chain; grid modernization software | Physical/regulatory timelines are long   | Pre-seed/Seed | Full scope      |

## About *Pathfinders Capital*

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***Pathfinders Capital*** is a ***Lab-to-Term Sheet***® early-stage investor. We invest at the pre-seed and seed stages across Enterprise IT and Deep Tech, with active current emphasis on cybersecurity and AI/ML. We look for founders solving hard, physically or mathematically constrained engineering problems — not incremental applications of commodity capability — and we bring genuine technical diligence to categories that reward it: adversarial security tooling, exposure management, autonomous systems, and the infrastructure layers underneath frontier science.

This report is part of our DeepTech Signal series, in which we read primary technology research and translate it into a working investment lens for founders and co-investors. Each of the ten technology areas of 2025 covered here is also published as standalone pieces on our website, with deeper treatment of the specific developments, examples, and reasoning behind our positioning.

We do not invest in Blockchain and Crypto, Consumer Tech, FinTech, or pure BioTech, Life Sciences, and Pharma without a genuine IT or deep-tech core — a boundary we've tried to make explicit throughout this report rather than blur for the sake of a broader narrative.

If you're building at any of the investable layers identified in this report, we want to hear from you.

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# Sources & Methodology

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## Sources

*McKinsey Emerging Technology Reports, BCG DeepTech Views, ETH Zurich, MIT and Stanford Emerging Technology Reports, World Economic Forum and Hoover Reports, IEEE, Nature, Spectrum Publications.*

## Methodology

This report and the accompanying ten-part DeepTech Signal blog series were produced by reading various emerging technology developments in academia, labs and private organizations. Facts, figures, and named examples are drawn from and attributed to different reports; all investment framing, sector positioning, scope determinations, and the “where we're looking” calls in each section are original analysis by **Pathfinders Capital** and do not represent the views of report publishers, or the report's authors and contributors.

Where various reports covered material outside Pathfinders Capital's investment mandate — therapeutics and clinical applications in biotechnology and neuroscience; blockchain, cryptocurrency, and central bank digital currencies in cryptography — this report and its companion blog posts say so explicitly rather than silently omitting the boundary.

## A Note on This Framework

This is a living document. We expect to revisit and update this framework as new emerging technology appears on the horizon and other primary technology research is updated in future years, and as our own active diligence sharpens or challenges the theses presented here.

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Palo Alto, CA

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