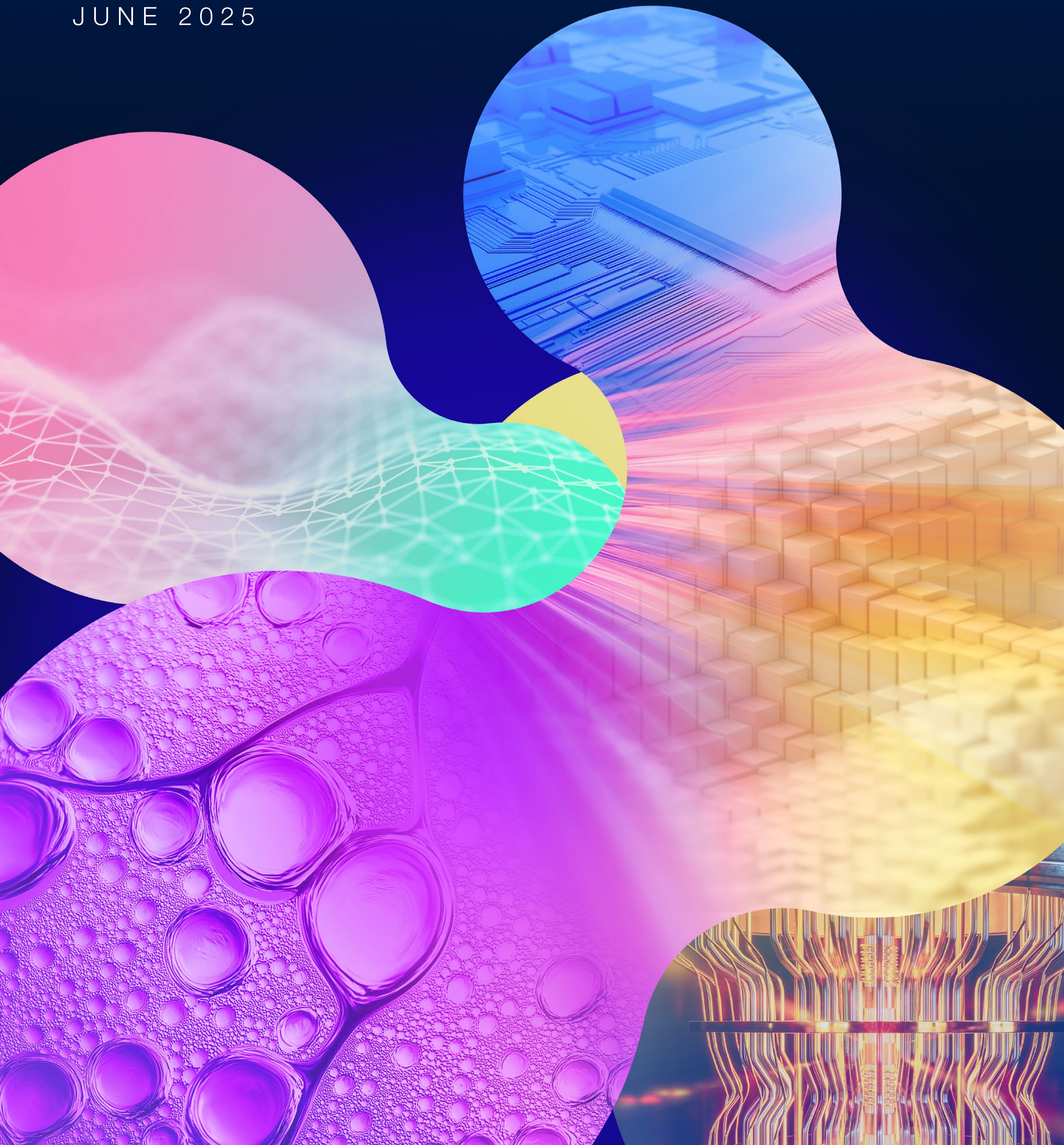
In collaboration with Capgemini

Technology Convergence Report

INSIGHT REPORT

JUNE 2025



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We are living through a pivotal moment in technological history where multiple foundational technologies are maturing, combining and accelerating in parallel. From artificial intelligence (AI) and quantum computing to biotechnology and advanced materials, this concurrent movement of technologies is reshaping industries and solving problems once thought impossible. Whether the steam engine, electricity, the computer or even the internet, technological progress has traditionally been framed through the lens of individual breakthroughs. However, today's complexities necessitate moving to a systems-thinking approach.

Technological progress has historically been framed through the lens of individual breakthroughs, though, as W. Brian Arthur observed in *The Nature of Technology*, innovations rarely evolve in isolation. Rather, they emerge from combinations of existing technologies to create new possibilities that themselves become building blocks for further innovation.

This systems-based understanding of innovation, when layered with the World Economic Forum's global multistakeholder perspective and Capgemini's practical applied insights, led to the development of the **3C Framework**. This framework captures how technologies evolve through stages of combination, convergence and compounding in a network-based view that helps organizations identify and capture value at technological intersections.

The insights in this report draw from both qualitative and quantitative sources. The Technology Convergence Community, composed of subject matter experts from the Forum's global network of business, academia, civil society, public sector leaders, provided domain expertise and case examples. This was complemented by Capgemini's global survey of 2,000 senior executives across 18 countries, 10 industries and five continents, offering a comprehensive view of convergence patterns and organizational readiness. Together, these insights were cross-referenced with examples of industry transformation and real-world case studies to uncover the implications of convergence for the future of innovation, competitiveness and policy planning. As economic, societal and climate urgencies grow, decision-makers must adopt a full-spectrum approach to innovation that moves beyond segmented thinking and embraces the thoughtful combination of multiple technological capabilities. Recognizing how intersectional technologies give rise to new industries, business models and economic paradigms is essential not only for navigating this rapidly changing environment but also for unlocking new pathways of value creation. By illuminating these technological interdependencies and their business implications, this collaboration aims to equip leaders with the foresight needed to navigate convergence strategically.

Executive summary

Multiple foundational technologies are maturing simultaneously, creating unprecedented opportunities for those who understand their combined potential.

The World Economic Forum has developed the 3C Framework, which reveals the patterns driving innovation transformation. It provides a map for navigating today's tech explosion, where breakthroughs don't stand alone but merge to reshape markets.

Technologies combine to create capabilities impossible through any single innovation.

Value chains converge, opening new market positions and revenue streams.

Benefits compound as adoption scales, accelerating further innovation cycles.

In the context of this framework, this report examines how eight powerful technology domains – artificial intelligence (AI), omni computing, engineering biology, robotics, advanced materials, spatial intelligence, quantum and next-generation (next-gen) energies – are combining to create value that no single innovation could deliver alone.

A total of 238 technology subcomponents were matched and filtered down to 23 combination patterns with established applications and profound recent breakthroughs. The analysis focused on meaningful intersections between technological subcomponents at different maturity stages. These combinations were chosen for their potential to influence innovation trajectories and highlight strategic opportunities across domains through convergence.

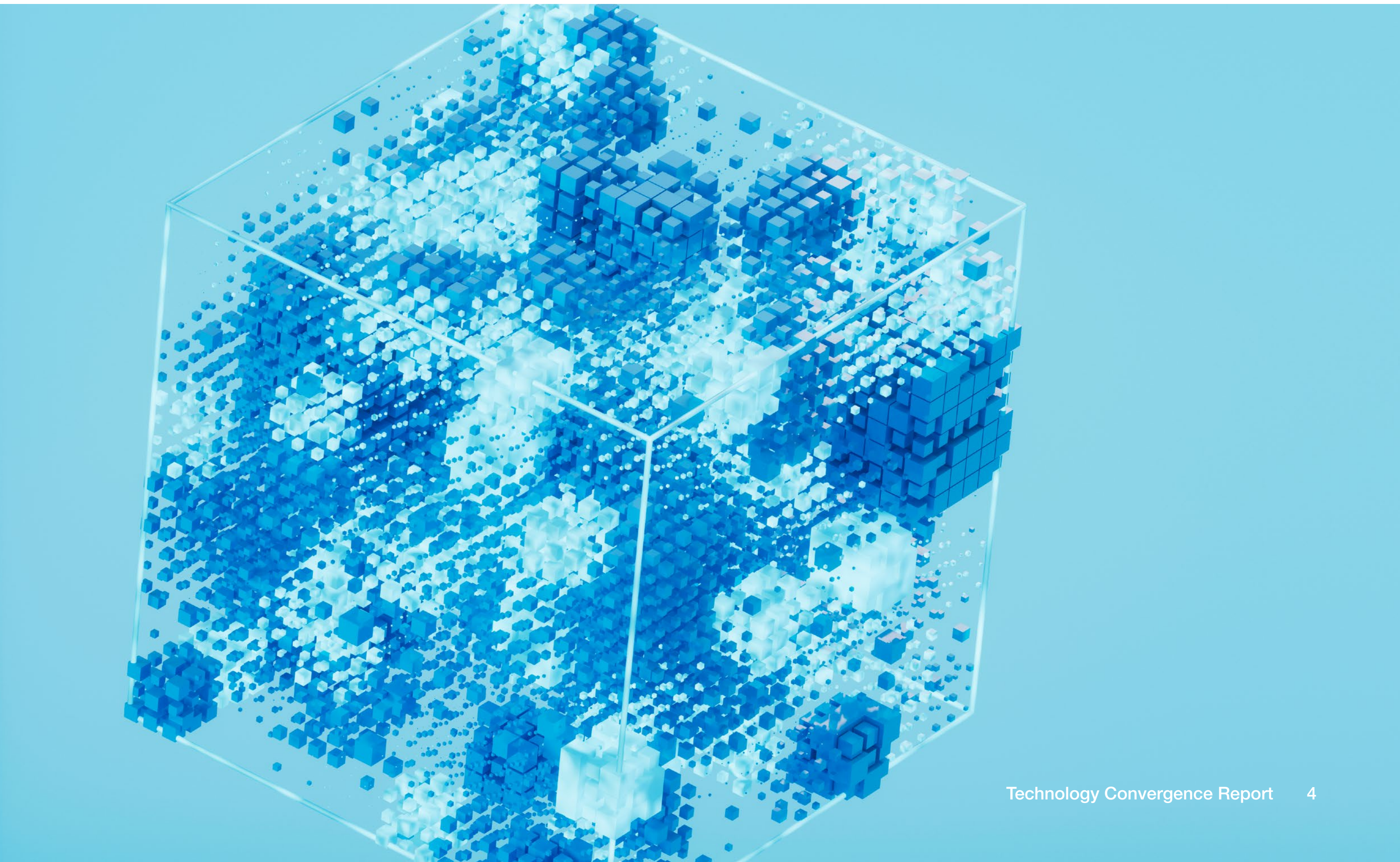


FIGURE 1 | **Patterns of technology domain combinations – overview**

Artificial intelligence

- Distributed edge intelligence networks
- Multi-agent autonomy
- Bio-inspired processing

Robotics

- Cognitive robotics systems
- Bio-inspired robotics
- Swarm robotics systems

Omni compute

- Decentralized intelligent system
- Internet of robotic things (IoRT)

Advanced materials

- Adaptative materials modelling
- Bio-engineered materials
- Energy optimization materials

Engineering biology

- Precision bio-production
- Bio computation platform
- Cell-cultivation system

Next-generation energy

- Intelligent grid system
- Renewable energy storage
- Decentralized energy market

Spatial intelligence

- Spatial processing
- Immersive platform
- Digital twin ecosystems

Quantum

- Hybrid quantum-classical computing systems
- Quantum enhanced measurement
- Quantum communication networks

Artificial intelligence · Omni compute · Engineering biology · Spatial intelligence · Robotics · Advanced materials · Next-gen energy · Quantum

The future lies in bold combinations. Companies that strategically combine technologies at different stages of maturity are positioned to gain, especially as cross-industry value chains give rise to entirely new product categories and business models. By applying the 3C lens, organizations can start identifying the technology pairings that align with their core capabilities, recognizing when shifts in maturity create new market openings, and investing strategically to unlock value as convergence accelerates.

1 The 3C Framework

A systems-level view of technology evolution helps navigate transformation waves – from combinatorial to compounding – for strategic and value creation.

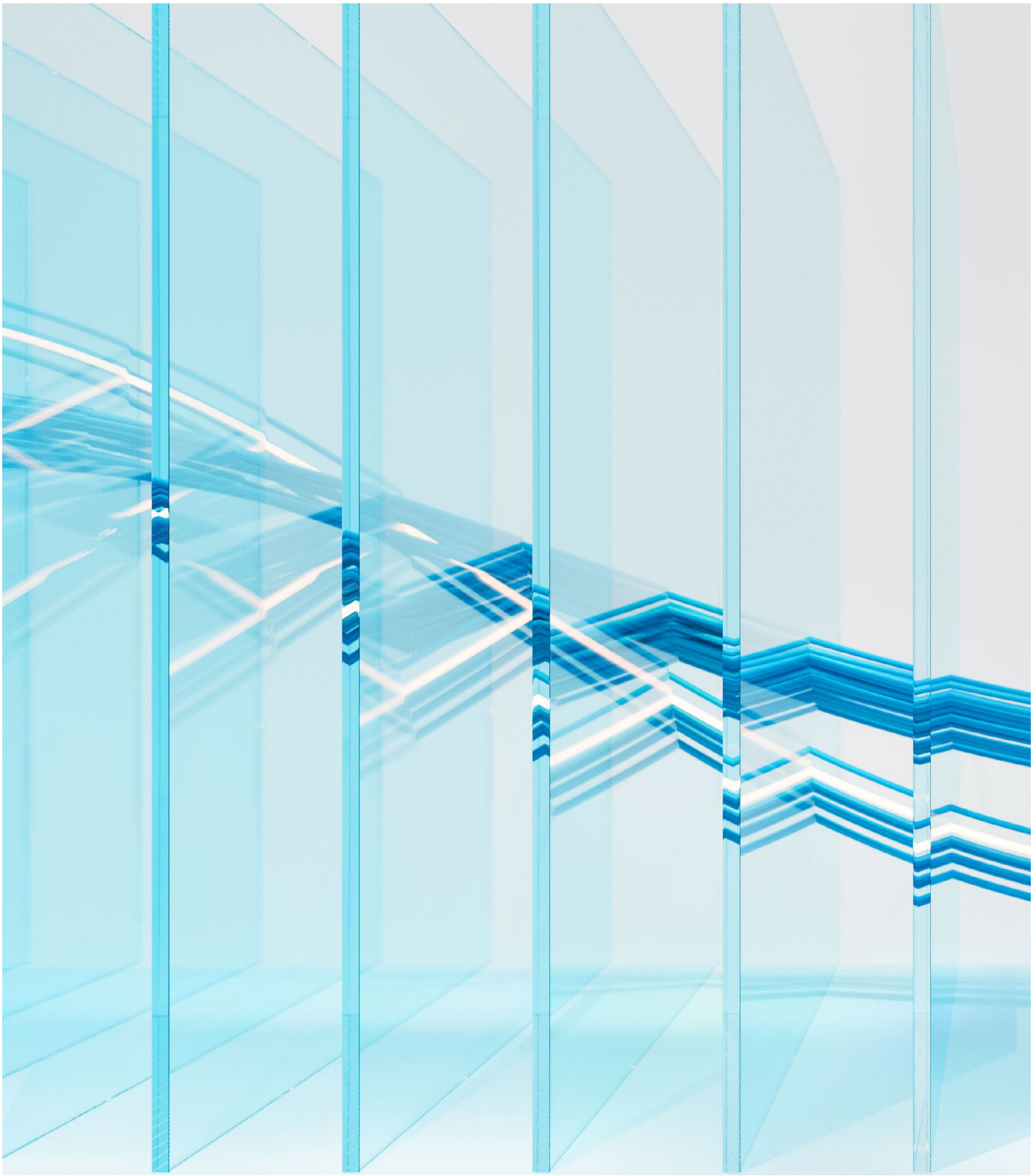
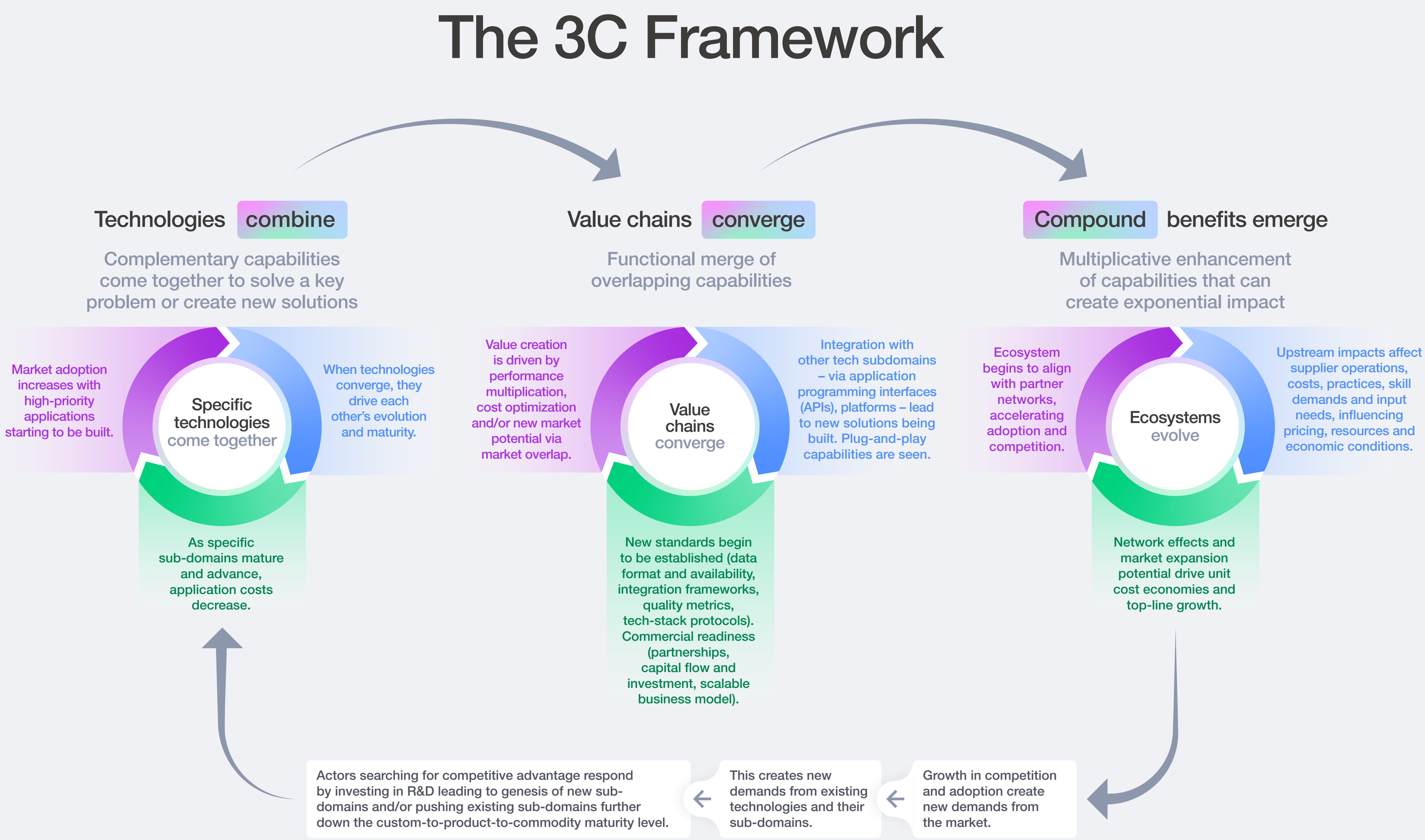


FIGURE 2 | **The 3C Framework's circles build upon each other, creating feedback loops that further fuel technological advancement and market evolution**



In a rapidly evolving technological landscape, multiple technological developments occur in parallel, each with variable trajectories, impact potentials and adoption timelines. This complexity creates a fundamental strategic dilemma: which technological developments deserve immediate attention and investment, and which remain too immature or isolated to drive significant business value? The 3C Framework offers a dynamic model for capturing the interplay of complementary innovations and understanding how technology creates value, through three interconnected stages:

- **Combination:** The integration of complementary technologies based on their level of maturity

- **Convergence:** When these technological combinations allow firms to migrate and participate in new value chains, thus converging existing value chains and allowing new entrants

- **Compounding:** When value chain convergence drives exponential adoption and cost reduction, creating ecosystem impacts and enabling further technological combinations downstream

This addresses how strategic value emerges from the momentum of integration, adoption and scale, and helps provide clarity on which combinations offer the greatest strategic opportunities, how they may illuminate new business models, and when they are likely to scale and deliver returns.

By systematically analysing technology development through the lens of combination, convergence and compounding, organizations can identify emerging opportunities faster, position for advantage within evolving value chains, and capture value adjacent to scaling technological transformations, aligning immediate business objectives and long-term market positioning.

1.1 Combination

The foundation of technological synergy

At the heart of technological innovation lies combination: the integration of discrete complementary technologies to create something fundamentally new. To understand this process, it's essential to consider **granularity**, or the degree to which technologies can be analysed at the sub-component level.

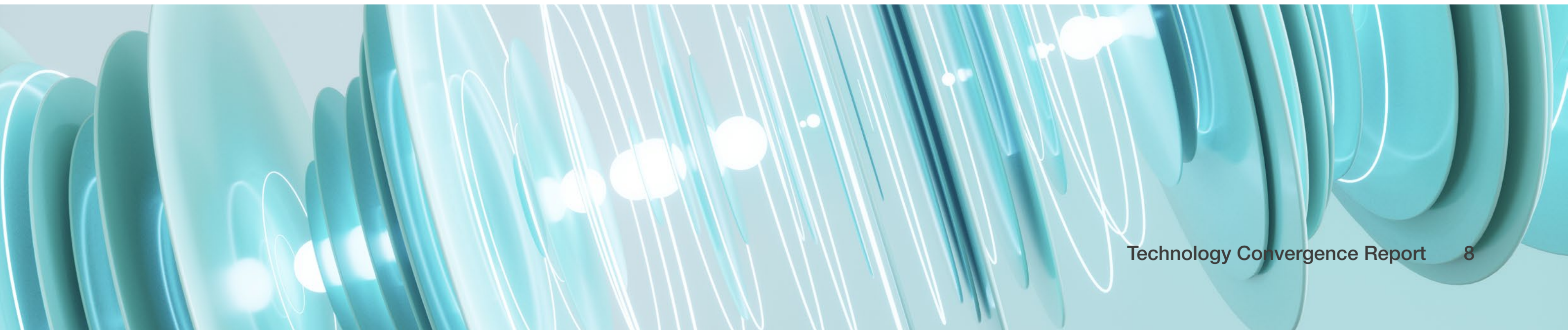
For example – artificial intelligence (AI) is a universal term for many subcomponents such as machine learning (ML), natural language processing (NLP), large language models (LLMs), neural nets and more. When progress in a technology domain like AI occurs, it is occurring at the sub-component level as they each evolve at different rates pushing the technology domain forward. For instance, from 2021 to the present, massive progress has occurred in the NLP/LLM field which is often cited as an advancement in AI more generally. The reality is more nuanced; the different sub-components – in this case graphics processing units (GPUs) and LLMs more specifically – of a technology have evolved at different rates to collectively push the technology domain forward.

More importantly, when technologies combine, it is at the sub-component level. The combination of AI and quantum technology involves the convergence of ML, quantum algorithms and quantum computing to create new solutions. Quantum algorithms are used to simulate phenomena (such as electronic structures, rovibrational spectra) at the atomistic level, while AI/ML is used for analyses and simulations of molecular phenomena (macromolecular structures, intermolecular forces). Thus, quantum ML blends models across both scales – atomistic and molecular to derive new insights into how materials are constructed, or how to modify them to make them more suitable for real-world applications.

The combination of AI and quantum technology involves the convergence of ML, quantum algorithms and quantum computing to create new solutions.

While, in theory, many technologies can be combined, not all combinations produce meaningful outcomes. An observation from this work is that the most valuable combinations tend to involve an interlock of technologies at **different maturity levels** – for example, pairing experimental innovations with stable, scalable infrastructure. These combinations strike a balance between novelty and deployment readiness.

Allocating limited resources across these maturity levels requires a disciplined approach to technology assessment that goes beyond traditional return on investment (ROI) calculations, requiring a balanced portfolio approach that considers future value and business model innovation potential.



1.2 Convergence

Reshaping value chains for higher returns

While technological combination creates capability advantage, convergence translates this advantage into revenue growth by reshaping value chains and opening new market opportunities. For decision-makers, convergence represents the critical phase where technology investments begin generating tangible business returns.

Convergence occurs when combinatorial capabilities merge with economic incentives to transcend traditional industry boundaries, dissolving established silos and forging interconnected value chains.

- **Margin expansion opportunities**: New integrated technology solutions typically command premium pricing compared to mono-component technologies, creating powerful incentives to expand beyond traditional value chain positions.
- **Recurring revenue potential**: Solutions that harness technological combination, in most cases, enable subscription and service-based models that transform one-time sales into repeatable, long-term revenue streams.
- **Customer relationship depth**: Combined tech solutions address more complex customer needs, creating deeper engagement and higher lifetime value.
- **Competitive differentiation**: Providing combined technology solutions provides sustainable differentiation that preserves pricing power.

The robotics market serves as a prominent example of the forms of new value capture. Industrial robots, once a core driver of automation, now deliver diminishing marginal returns. Most operate in highly controlled environments and are optimized for repetitive, rule-based tasks. As this segment matures, firms face flattening performance gains and shrinking differentiation opportunities from further iteration. The economic imperative to find new growth vectors is pushing companies to explore adjacent markets and platforms.

Value chain expansion within existing markets

Tech combination enables organizations to extend their footprint across an existing value chain, capturing additional margin from existing customer relationships while limiting competitive exposure.

CASE STUDY 1

Blue Ocean Robotics

Rather than remaining confined to traditional hardware manufacturing, Blue Ocean Robotics adapted their product with AI and spatial computing capabilities to extend their offerings to include collaborative solution architectures and joint development processes with their partners.[1,2]

This strategic evolution has transformed them from a component supplier to a full-service innovation partner, significantly increasing revenue per customer while deepening strategic relationships. By expanding across the value chain, they now capture service revenue, integration fees and ongoing optimization value that hardware-only players cannot access.

New category creation through cross-industry convergence

More transformative value chain convergences occur when entirely new product categories are made by combining technologies in ways that redefine market boundaries and address previously unsolvable challenges.

CASE STUDY 2

Humanoid robots in China

Recent breakthroughs in vision-language-action models (VLA), spatial intelligence algorithms and cross-domain systems integration have unlocked new possibilities for humanoid robotics. VLA models and AI agents now enable robots to interpret multimodal instructions, learn from diverse inputs and make autonomous decisions in complex settings. Meanwhile, innovations in spatial intelligence such as Gaussian splatting and spatial reasoning allow machines to perceive and navigate human environments with greater precision and adaptability. Finally, technologies from adjacent industries including mobility control, sensor fusion, battery systems and user interface design are being recombined to support the physical form and real-world functionality of humanoid robots.

In response, Chinese firms from sectors such as consumer electronics, drones and autonomous vehicles are repurposing their existing capabilities to build humanoid platforms that can operate in unstructured, everyday environments like homes, hospitals and warehouses.

TABLE 1 **Transition of core competencies to humanoids for Chinese firms**

Company	Core capabilities	Humanoid-enabling capabilities
Xiaomi →	Consumer electronics miniaturization, battery systems, user interface (UI)/user interface (UX) design	Physical design and integration of humanoid hardware with intuitive human-machine interfaces, connected to home ecosystems
DJI[3] →	Drone flight control, sensor fusion, autonomous navigation	Navigation and real-time environmental awareness for mobile robots and autonomous systems
Li Auto[4] →	Vehicle autonomy systems, Mind GPT AI models	Multimodal reasoning, command interpretation and autonomy in dynamic physical settings
Baidu and UBTech[5] →	AI expertise, Apollo autonomous driving platform	Human command interpretation and complex environment navigation for general-purpose humanoids

In China, this cross-industry convergence is driving remarkable economic efficiencies. Today, building an identical robotic arm in the US (e.g. Universal Robots' UR5e) costs approximately 2.2 times more than in China,[6] largely due to China's closely net integrated manufacturing ecosystem. As the world moves towards increased autonomation where robots manufacture other robots,[7] this cost advantage, combined with cross-industry capability sharing, is accelerating the humanoid market development – with projections showing humanoid robot shipments growing from 18,000 units in 2025 to over 1 million by 2030.[8]

For organizations navigating convergence opportunities, several critical questions must guide their strategic positioning thinking:

1. **Value chain leverage:** Which positions provide maximum leverage over emerging value chains while building on existing organizational strengths?
2. **Integration economics:** Where does technology integration create sufficient value to justify premium pricing and market development investments?
3. **Capability requirements:** What new skills, partnerships and organizational structures are needed to execute effectively in converged value chains?
4. **Market timing:** When will technological combination solutions reach sufficient scale to deliver significant returns on strategic investments and justify the effort to migrate into new or adjacent value chains?

Organizations seeking to excel at identifying and capturing convergence opportunities must maintain disciplined focus on economic fundamentals while continuously evaluating how technological evolution creates new value chain positioning options. They need to recognize that successful convergence strategies begin with a clear understanding of customer economics and value creation potential, rather than over-focusing on technological combinations alone. By systematically analysing how technology combinations reshape value chains, leaders can identify emerging revenue streams before competitors recognize the same opportunities, positioning their organizations to capture disproportionate value.

This is exemplified today in the healthcare industry, where organizations are combining genomic sequencing technology (custom), AI diagnostic models (product) and electronic health record systems (commodity) to create personalized treatment protocols (Figure 4). Solutions such as UPMC's Enhanced Detection System for Healthcare-Associated Transmission (EDS-HAT), which combines ML with whole genome sequencing and EHR data, are saving hospitals as much as $700,000 over a two-year period through improved infection control.[9]

1.3 Compounding

Exponential ecosystem impacts through scaled adoption

Once convergence takes hold, compounding effects drive exponential adoption and cost reductions. The compounding stage transforms promising convergence plays into market-defining forces through scale economics, network effects and ecosystem dynamics. Two reinforcing mechanisms drive compounding effects:

1. **Firm-level scale economics:** As combined tech solutions gain market adoption, organizations benefit from traditional scale economics, including:

- **Production efficiencies:** Unit costs decline as fixed development costs are spread across larger volumes. For example, a logistics company deploying AI-enhanced robotics might slash delivery costs by 25% as adoption scales.
- **Learning effects:** Performance improves as organizations accumulate implementation experience. In the same example as above, the logistical company using robotics uses the data it collects to refine its AI, further boosting efficiency.
- **Business model innovation:** The above changes impact the scaling capabilities of the early adopter, enabling new pricing and delivery models, not possible at lower volumes or for other ecosystem actors to match – unless they adopt the same tactics.

2. **Ecosystem network effects:** Beyond firm-level benefits, compounding creates powerful ecosystem dynamics that further accelerate adoption and value creation:

- **Standards emergence:** As solutions scale, de facto standards emerge that reduce integration costs.
- **Complementary innovation:** Third parties develop complementary products and services that enhance core solution value.
- **Supply chain maturation:** Specialized suppliers emerge to deliver components at lower costs and higher quality.
- **Regulatory adaptation:** Governance frameworks evolve to accommodate new technologies, reducing compliance uncertainty.

Strategy leaders who recognize these ecosystem dynamics can position their organizations to capture disproportionate value by establishing positions that benefit from complementary innovations or by creating dependencies that lead to long-term competitive advantage.

CASE STUDY 3

The electric vehicle ecosystem

The compounding effects in electric vehicle (EV) adoption illustrate these dynamics. Initial adoption faced challenges of high vehicle costs, limited range and inadequate charging infrastructure. As adoption has scaled, battery costs declined by 90% over the past 15 years,[10] charging networks expanded from isolated corridors to comprehensive coverage, and regulatory frameworks evolved to support electrification through incentives and standards.

Organizations that recognized these compounding dynamics early secured advantageous positions in establishing battery manufacturing scale, securing critical mineral supply chains and developing proprietary charging technologies that created lasting competitive advantages as the market matured.

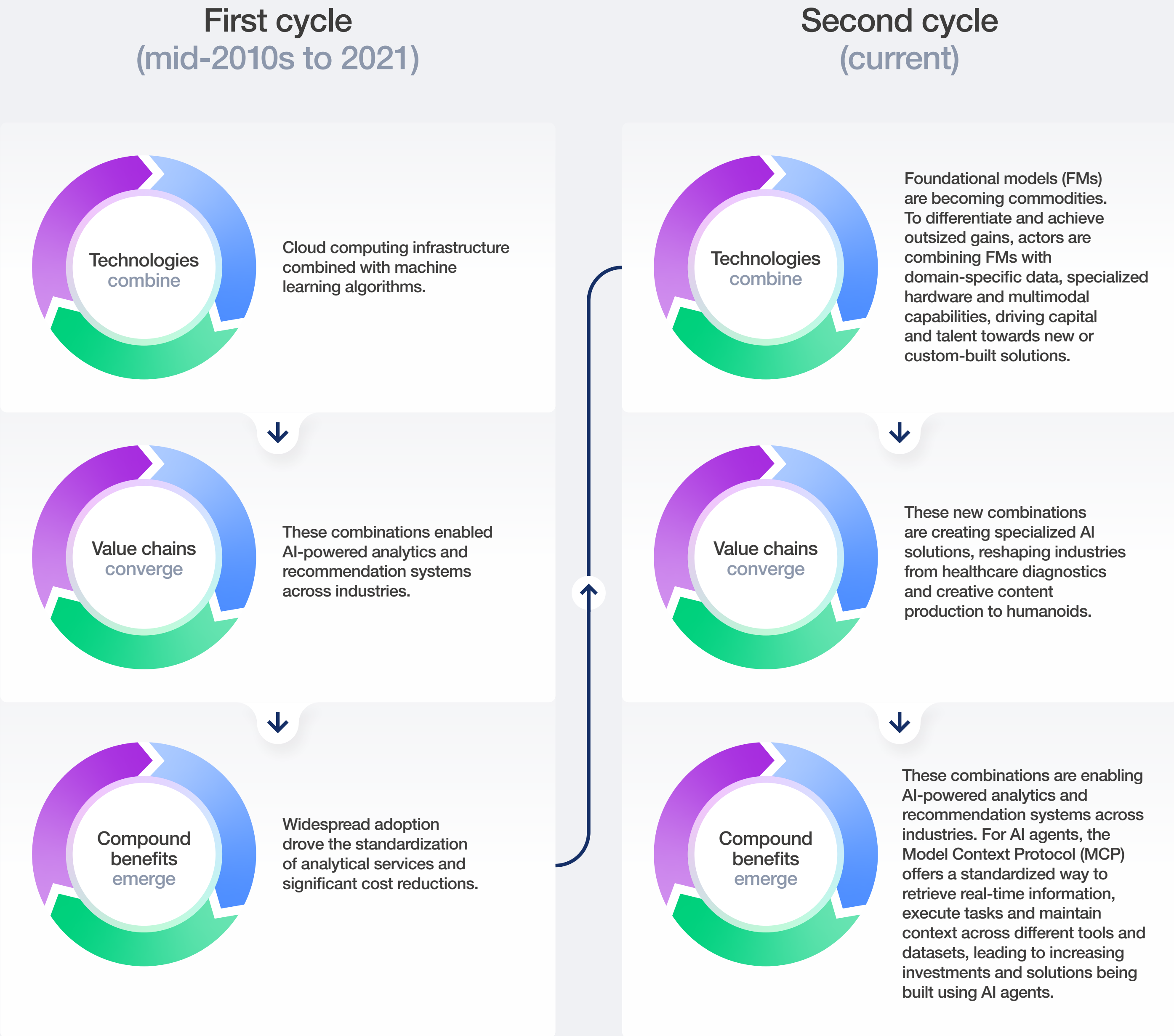
For executive decision-makers, the compounding phase requires strategic patience combined with aggressive execution. They must maintain investment through early adoption challenges while constantly optimizing for scale as markets develop. Organizations that master this balance achieve what appear to be "overnight successes" that actually result from years of strategic positioning for inevitable compounding effects.

Compounding should not be viewed as a final stage of a process but as a catalyst for the next wave of technological combinations that creates a self-reinforcing cycle.

The cycle activates when compounding standardizations inspire firms to seek new technological combinations, otherwise known as "The Innovator's Dilemma". Early adopters of converged technologies who captured premium margins find their competitive advantages gradually reduced as technologies become widely available at decreasing costs. Standardization is beneficial for the ecosystem but presents a strategic challenge for individual companies seeking continued differentiation.

NVIDIA exemplifies this cycle. As general-purpose GPUs became standard for AI training, NVIDIA recognized the need for new combinations to maintain its market advantage. The company invested heavily in combining its hardware expertise with specialized AI software frameworks (CUDA, cuDNN) and application-specific integrated circuits. This strategic pivot towards new combinations allowed NVIDIA to capture extraordinary value as AI compounding accelerated – increasing its market capitalization from approximately $300 billion to over $3 trillion in just three years. Similarly, as LLMs reach compounding scale and standardize through application programming interface (API) access, companies like Anthropic and OpenAI are already pursuing new combinations – integrating LLMs with agent architectures, specialized reasoning capabilities and domain-specific training techniques – to create the next wave of differentiated AI applications.

FIGURE 3 | 3Cs in the context of AI – a contemporary illustration



2

Eight advanced technology domains

AI, omni computing, engineering biology, spatial intelligence, robotics, advanced materials, next-generation energies and quantum are the report's foundations of analysis.

> This research provides a structured mapping of technology combinations from eight advanced domain areas that organizations can use as a starting point for further strategic alignment and capability development.

To compete effectively in an era of combinatorial innovation, organizations must determine which combinations align with their unique strengths. This research provides a structured mapping of technology combinations from eight advanced domain areas that organizations can use as a starting point for further strategic alignment and capability development.

The domain areas selected – AI, omni computing, engineering biology, spatial intelligence, robotics, advanced materials, next-generation (next-gen) energy and quantum technologies – were identified through expert consultation and global survey validation as among the most consequential in shaping near- and mid-term innovation trajectories. Reflecting the combinatorial nature of modern technological advancement, each domain was disaggregated into its core sub-domains and technology components. The final taxonomy comprises 238 technology sub-components.

Each sub-component was assessed using a maturity model created based on Simon Wardley's four-stage classification framework. This framework provided a consistent basis for understanding how technologies evolve and where they sit in the innovation life cycle:

– **Genesis-stage technologies** often serve as research-driven catalysts, waiting for practical application. They serve as differentiators or future option values, and while they may not generate immediate returns, selective investment in these technologies secures potential future competitive advantages and signals innovation leadership to customers and partners.

– **Custom-built technologies** are adaptable but require specific market alignment to scale. While they address specific market needs that commercial off-the-shelf solutions cannot meet, their differentiation factor needs to be aligned with customer needs to justify dev costs.

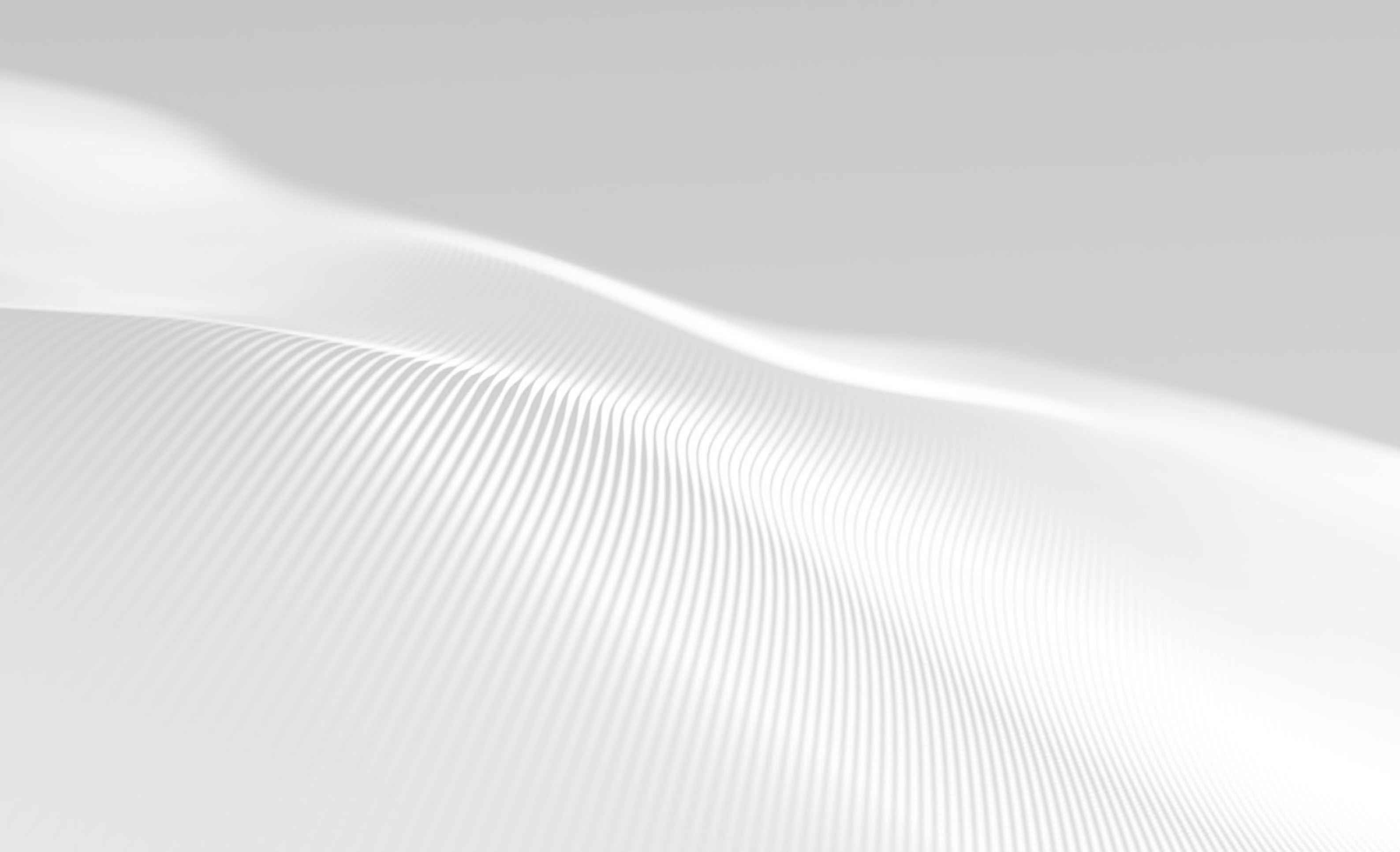
– **Product-stage technologies** are ripe for integration and often act as enablers for value chain convergence. They provide the practical capabilities that deliver immediate customer value and represent the core of most technology portfolios. They often serve as platforms for integrating both more experimental and more commoditized components.

– **Commodity-stage technologies** provide the infrastructure backbone that allows new technologies to scale efficiently, thus creating ecosystem impacts. They deliver cost efficiency and scalability. By employing industry-standard components and infrastructure, organizations can reduce operational costs and focus resources on higher-value differentiation.

FIGURE 4 **Mapping of technology maturities and their characteristics**

	Genesis	Custom-built	Product	Commodity
Adoption	Emerging, experimental phase	Early adoption, bespoke solutions	Standardization and defined performance metrics	Mature, widely available, plateau in core performance metrics
Market	High variability in implementation	Growing but fragmented market	Clear market leaders in established market	Price-based competition
Standards	Limited standardization	Early standardization attempts, emerging best practices	Established standards	Universal standards
Cost	High cost per unit	Declining (but still high) costs	Predictable cost structure	Optimized costs
Value creation	Value proposition under exploration	Clear value for specific applications	Strong value proposition	Optimized value delivery
Implementation	Requires highly specialized expertise	Requires highly specialized expertise	Standard skill sets application	Common skill sets sufficient

Note: This figure was inspired by Simon Wardley's Value Chain Mapping methodology.



Once maturity ratings were assigned, technology combinations were systematically constructed and then filtered to retain only those already demonstrating cross-industry application – an indicator of both current scaling activity and convergence potential. A recurring pattern emerged wherein the most effective combinations typically span multiple stages of maturity, reflecting a dynamic straddling innovation and deployment. Lower-maturity technologies often require significant development and integration effort, while higher-maturity technologies – though stable and easily deployable – rarely deliver breakthrough value unless combined with novel, experimental components.

Linkages across domains

The analysis revealed recurring interaction patterns among technologies as often complementary, inverse or mirrored in nature appearing across multiple domains. This is not coincidental; rather, it reflects the way different industries emphasize distinct facets of shared technological shifts, shaped by their specific operational challenges and strategic opportunities. The ensuing structure enables both a domain-specific and system-level understanding of how convergence is reshaping innovation across sectors.

2.1 AI domain

> Agentic AI is enabling autonomous decision-making and collaboration between intelligent systems, representing the genesis stage of maturity where innovation first takes form.

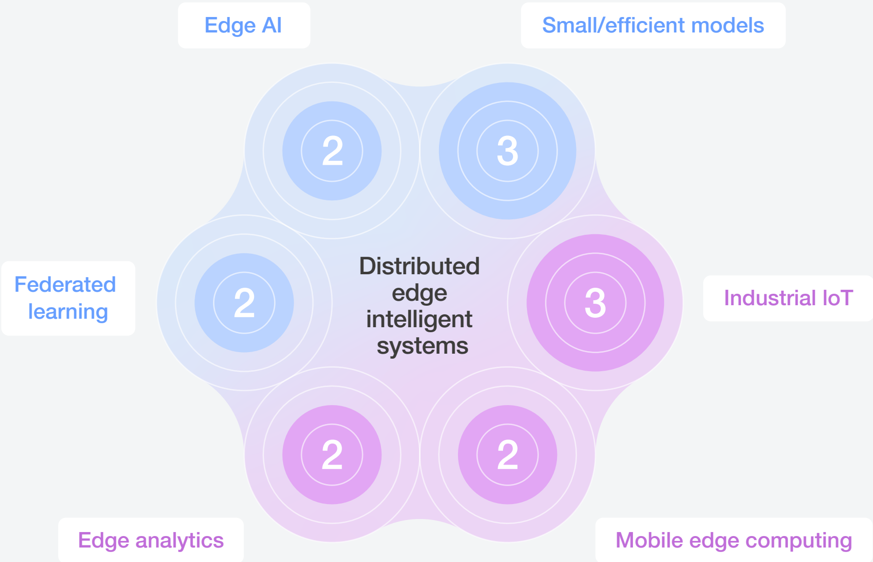
AI is becoming more powerful and more versatile. As a general-purpose domain, it presents a dynamic breadth of subcomponents in a layered maturity landscape that makes it a unique interlocutor for integrating, enhancing and embedding across all other domains.

At the cutting edge, agentic AI is enabling autonomous decision-making and collaboration between intelligent systems, representing the genesis stage of maturity where innovation first takes form. Custom-built technologies like edge AI deliver faster on-device processing for real-time applications, while federated learning improves data privacy through distributed model training, and reinforcement learning enhances adaptability in complex environments. These innovative components don't operate in isolation but integrate with well-established product-stage AI elements such as neural networks and predictive analytics, which have matured to provide the stability necessary for large-scale deployments. Finally, technologies like computer vision have approached commodity status, with standardized implementations now powering critical applications from factory monitoring to autonomous vehicles and medical imaging.

Distributed edge intelligence networks

Distributed edge intelligence networks fundamentally reimagine the computing landscape by embedding AI capabilities directly at the network periphery where data originates, creating an intelligent mesh of computational nodes that process information locally rather than relying on centralized facilities. This combination enables organizations to extract value from their internet of things (IoT) devices, sensors and other data-generating technologies without the infrastructure costs and vulnerabilities associated with centralized processing.

This combination is particularly evident in how federated learning transforms the fundamental approach to AI model development. Rather than centralizing sensitive data for training, federated learning distributes the training process across edge devices, allowing models to learn from local data without ever transferring it to centralized servers. Only the insights (model updates) travel across the network, dramatically reducing data exposure while still enabling collective intelligence improvement. When combined with specialized edge AI algorithms and hardware, these systems achieve both privacy protection and computational efficiency that would be impossible with any singular technology.



Technology domain

Artificial intelligence

Omni compute

Maturity level

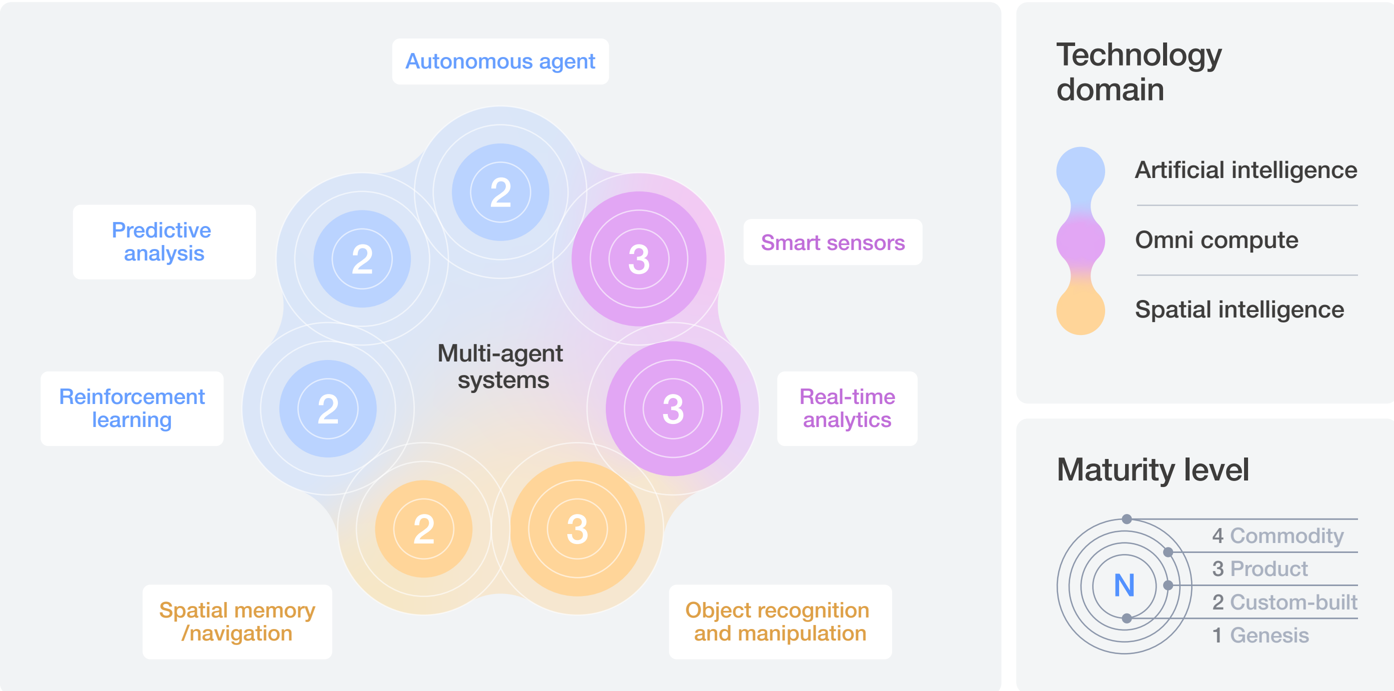
Industry	Company	Outcome
Energy and utilities	Vestas	Intelligent processing optimizes wind energy infrastructure by improving turbine efficiency, enabling predictive maintenance and maximizing renewable generation.
Telecommunications	Zetic.ai	Distributed processing in remote, bandwidth-constrained environments delivers improved safety, responsiveness and operational efficiency.

As organizations increasingly deploy IoT devices, sensors and other data-generating technologies at the network edge, this combination pattern enables them to extract value from that data without the infrastructure costs and vulnerabilities associated with centralized processing.

Multi-agent autonomy

The combination of AI agents with spatial intelligence and omni computing is creating a new generation of systems capable of making independent decisions in complex, real-world environments and collaborating as multi-agent systems. These coordinated collectives can distribute tasks across specialized agents, with some handling logistics, others quality control or maintenance prediction, while maintaining unified goals, similar to a digital workforce operating at machine speeds. This represents a fundamental shift from traditional rule-based automation to dynamic, context-aware systems that can respond to uncertainty and changing conditions. The systems make decisions based on real-time information, learn from outcomes and continuously improve their performance without human intervention.

Agentic AI provides the decision-making framework, while reinforcement learning enables these systems to improve through experience rather than explicit programming. Spatial intelligence and computer vision give the system situational awareness, allowing it to understand and navigate complex environments. When integrated with advanced robotics, these technologies create machines that can not only perceive and analyse but also physically act on their decisions (see section 2.5).

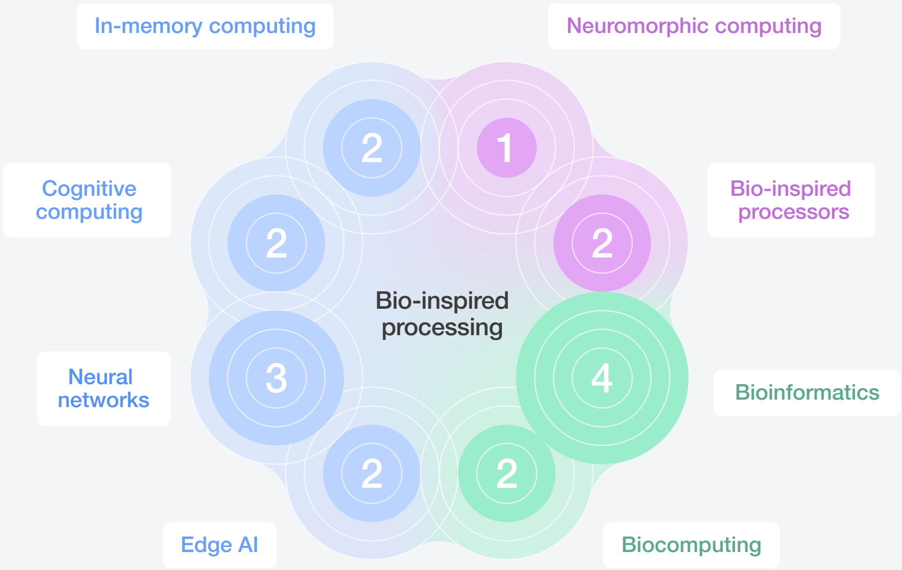


Industry	Company	Outcome
IT	DeepSeek	DeepSeek's novel counterfactual preference optimization reinforcement learning technique significantly enhanced reasoning capabilities while reducing hallucinations in LLMs. By open-sourcing these advancements, they democratized access to cutting-edge AI, enabling researchers and smaller organizations to build upon state-of-the-art capabilities.
IT	Salesforce	Agentforce could accelerate access to customer relationship management (CRM) data, transforming personalized customer interactions and enabling companies to deliver faster, improved experiences at scale.

Bio-inspired processing

Bio-systems represent the emerging approach to computational architecture that mimics nature's most sophisticated information processing system – the human brain itself. This would be a fundamental shift from traditional von Neumann architectures.

The integration of neuromorphic computing with biological principles is opening new frontiers in energy-efficient, adaptive computing that could potentially handle complex tasks with a fraction of the power consumption of traditional systems. By using AI-driven, in-memory computing and edge AI, these systems are better at real-time learning, pattern recognition and adaptive decision-making.



Technology domain

- Artificial intelligence
- Omni compute
- Engineering biology

Maturity level

Industry	Company	Outcomes
High-tech industry	SynSense	Neuromorphic edge processors can deliver real-time intelligence with ultra-low power for consumer tech, robotics, IoT and autonomous systems.
Automotive industry	BrainChip	Neuromorphic edge AI for automotive applications delivers real-time processing of light detection and ranging (LiDAR), radar and camera data to enable advanced driver-assistance systems.

Convergence transformation

The synergy of AI and omni compute enables firms to innovate beyond their conventional boundaries, pursuing higher returns by tapping into emerging markets while addressing the increasing needs of computational power on devices. Companies that primarily operated within a software-focused value chain are expanding into hardware solutions capable of maintenance, predictive analytics and healthcare monitoring.

Conversely, the integration of software into advanced systems is creating a new class of products. For example, Waymo is disrupting the automotive industry with its custom foundation model that incorporates multimodal sensor data (LiDAR, radar and camera) into its vehicles.

A clear shift is under way in investment patterns: from hype-cycle-driven funding to strategic investments in AI convergence platforms that integrate multiple technologies. In 2024, AI dominates venture capital flows, and while investor uncertainty remains, the convergence of AI with automation, robotics and edge computing is a recurring theme in the fastest-growing technology sectors. This trend is reflected in strategic investments by major players such as Intel, NVIDIA and SoftBank, as well as public initiatives like the European Union's funding for edge-AI tech projects.[11] As AI components become increasingly sophisticated, investment is flowing towards maturity-driven technologies that enable the development of integrated, real-world solutions and accelerating the next wave of intelligent systems.

The rapid evolution and widespread adoption of AI have further driven global governments to accelerate the development of regulatory frameworks[12] to manage its impacts effectively. The European Union's AI Act, now in effect, serves as a significant precedent for comprehensive AI regulation, laying down harmonized rules to govern the development and deployment of AI systems. The US, Canada, Brazil, the Association of Southeast Asian Nations (ASEAN), Japan and China are also developing their own regulatory approaches. Governments are increasingly focused on establishing national AI champions and AI skills hubs, and building national AI strategies to strengthen their competitive positions in the global AI landscape.

CASE STUDY 4

Anthropic – Model Context Protocol

Anthropic has developed an open-source Model Context Protocol (MCP) to transform how AI models interact with external data and tools. As LLMs scale, traditional deployments face growing complexity in context management, such as information silos, limited data accessibility and poor interoperability. MCP addresses these challenges by structuring how information flows into and between models, especially in multi-agent or tool-rich environments.

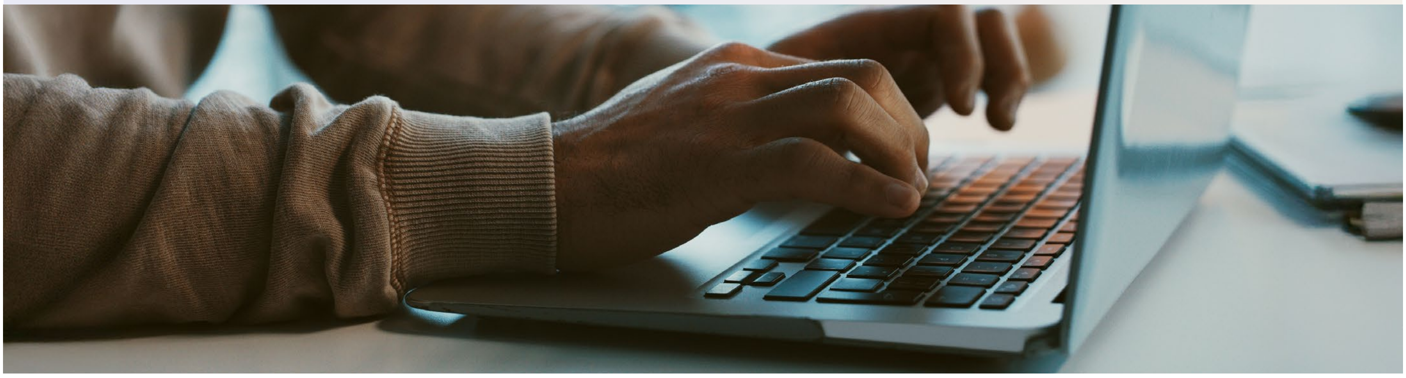
MCP improves efficiency by enabling one-time integrations that work across multiple platforms, saving time and resources. It also enhances context awareness for smarter assistants, real-time processing and coordinated tool use.

Open standard for complex agentic workflow

Because an MCP client can connect to multiple servers at once, an AI agent can combine tools. For instance, an AI operation agent might use one MCP to monitor equipment status, another to access data from ERP system and a third to schedule maintenance, all within a single conversation. This enables improved decision-making and execution.

Shared workspace for collaborating agents

Specialized AI agents focused on research, planning or execution can use MCP to dynamically exchange information and coordinate tasks in real time. By accessing a shared toolset through MCP, agents eliminate the need for direct system integrations, enabling faster collaboration, greater modularity and scalable orchestration across complex workflows.



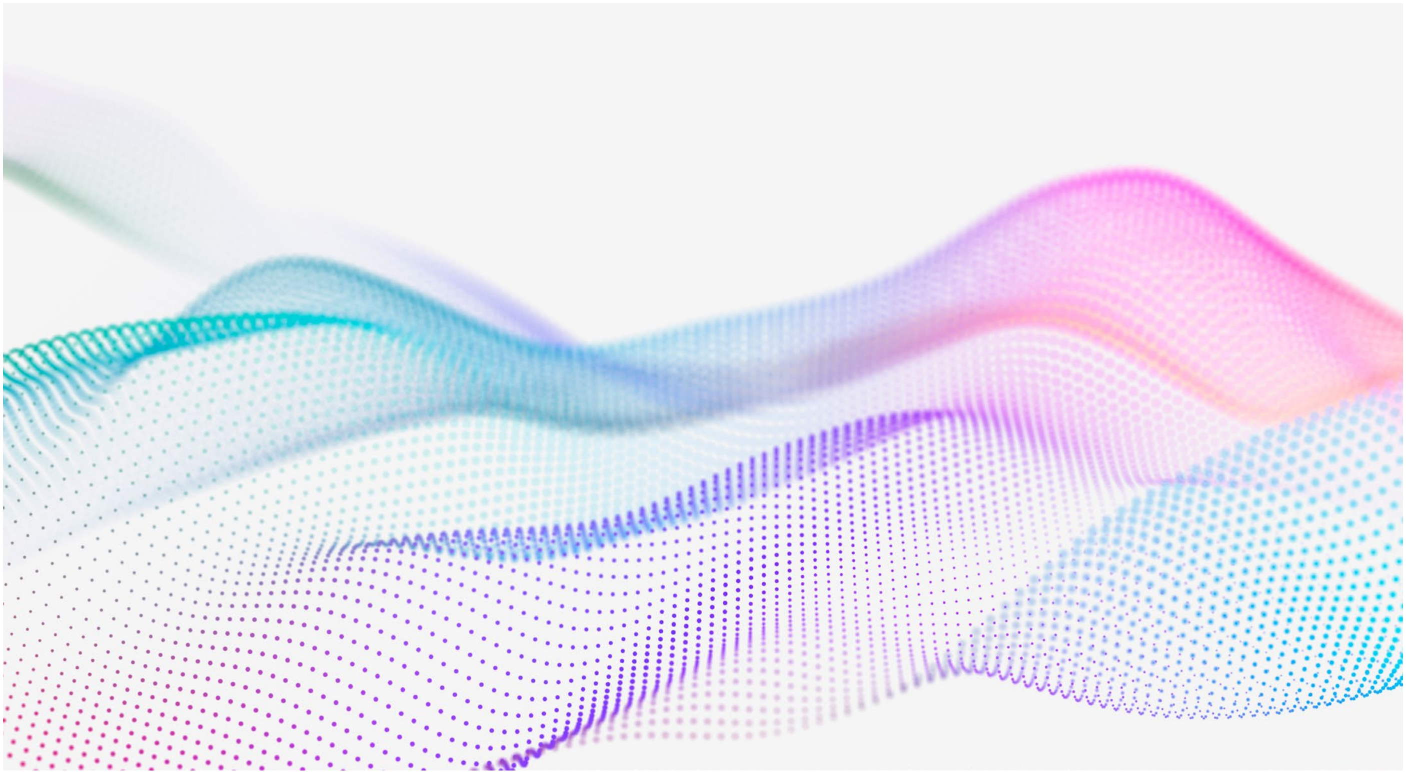
On the horizon

AI has advanced significantly in recent years, but few breakthroughs have happened overnight, no matter how sudden they may seem. Even now, the journey is still in its early stages, and new technology combinations driven by AI will continue to reshape industries and unlock the next wave of innovation.

As AI continues to drive technological innovation, the next frontier will be shaped by increasingly autonomous, small, efficient and multi-faceted intelligence systems working together. These hybrid intelligence architectures will get away from a one-size-fits-all approach and bring new sophistication and specificity to AI's applications.

These architectures integrate traditional ML for recognizing patterns in structured data, generative AI for producing new content and adaptive responses, and embodied AI that operates across distributed environments to interact with and respond to the physical world. The ability to fluidly switch between these different capabilities will enable even more flexible and customized decision-making.

Furthermore, the emergence of self-optimizing AI networks as a dominant pattern is anticipated. Today's systems are expected to continuously improve their own performance by learning from operational data without human intervention. However, this progression isn't automatic – further advancements in autonomous reasoning capabilities and system maturity will be necessary prerequisites.



2.2 Omni computing domain

Omni compute represents a distributed, democratic and decentralized computing landscape, where computation is brought closer to the data source rather than the current paradigm of high dependence on centralized cloud infrastructure. The rapid advancement of computational power and access is enabling increasingly complex integrations and applications while reducing cybersecurity risks by mitigating centralized vulnerabilities and strengthening data resilience.

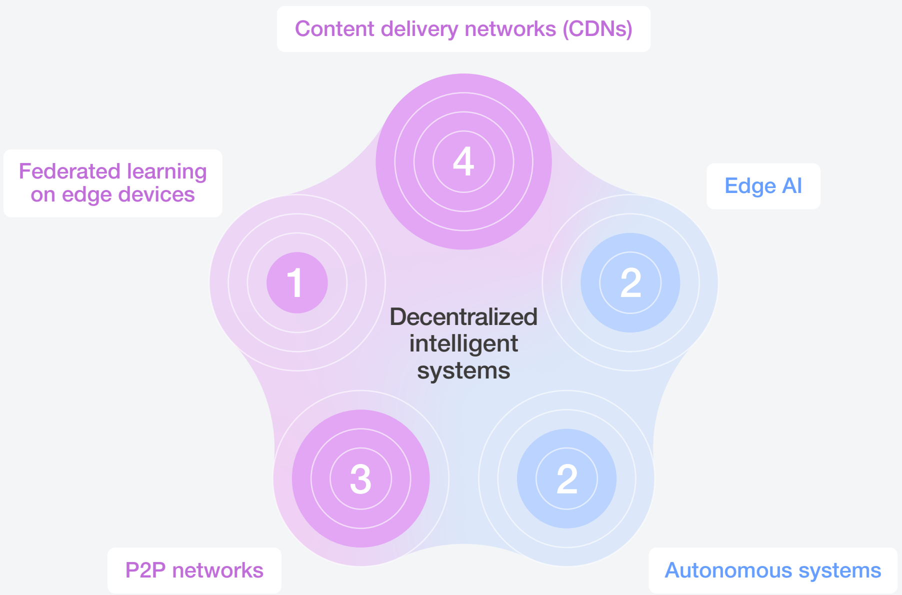
Neuromorphic computing and bio-inspired processors are enabling energy-efficient and adaptive computation, while embedded ML and mobile edge computing are facilitating real-time data processing directly on devices. Meanwhile, advancements in software-defined networking (SDN), wireless sensors and real-time processing ensure the reliability and scalability required for large-scale applications. SDN enhances network efficiency and flexibility, wireless sensors enable seamless data collection and transmission, and real-time processing powers mission-critical applications in AI, energy systems and robotics.

Decentralized intelligent systems

Decentralized intelligent systems fuse blockchain's trust architecture, peer-to-peer (P2P) networking and edge-centric AI to tackle computing's dual crises: the energy inefficiency of centralized data processing and the fragility of data privacy in interconnected systems.

In addition to federated learning, blockchain adds cryptographic accountability, ensuring AI workflows (e.g. model updates in a supply chain network) are verifiable and tamper-proof without third-party oversight. The addition of P2P networks and content delivery networks (CDNs) dynamically allocate resources, cutting latency compared to traditional cloud pipelines.[13,14]

The system's scalability stems from incentive-aligned participation where blockchain tokens reward contributors of edge compute resources (e.g. idle GPUs in a P2P grid), facilitating a self-sustaining ecosystem. The result is a resilient infrastructure where privacy isn't a trade-off but a foundational feature, and energy efficiency scales organically with network growth.



Technology domain

- Omni compute
- Artificial intelligence

Maturity level

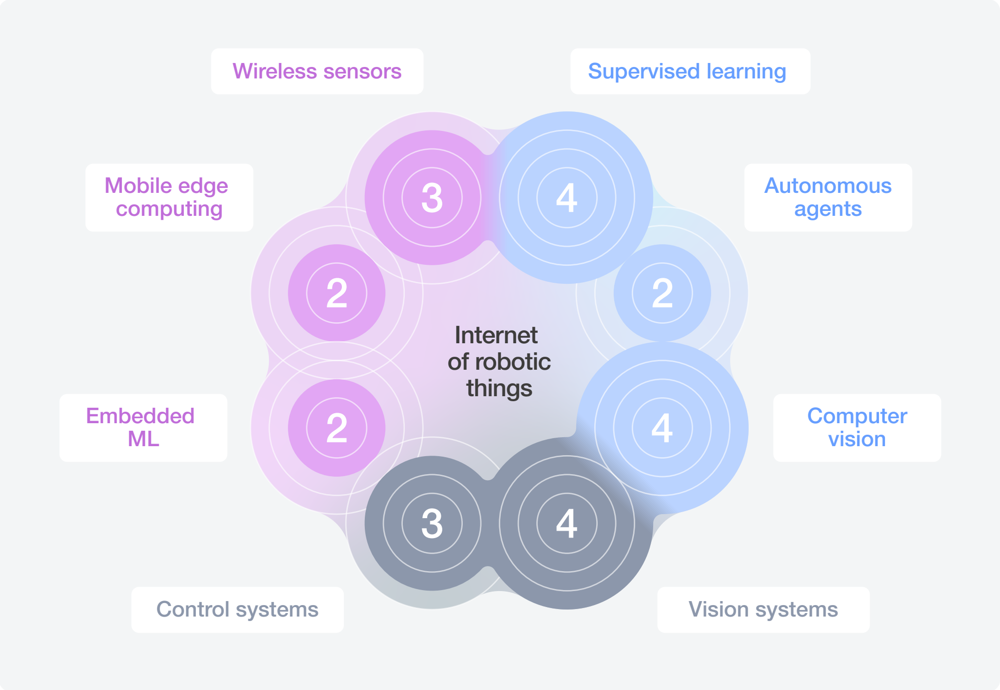
Industry	Company	Outcomes
IT	Seal Storage	Decentralized cloud storage delivers secure, verifiable, and sustainable data management for research enterprise and Web3 applications.
Financial	Aave	Aave is a decentralized and open-source protocol that offers a variety of financial tools and services, allowing for greater accessibility and financial transparency.

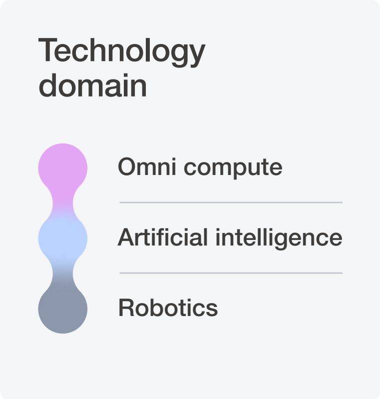
Internet of robotic things (IoRT)

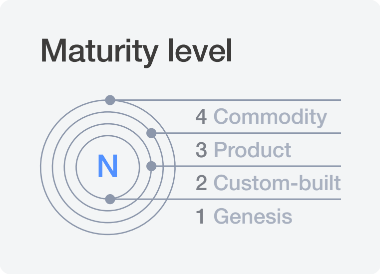
IoRT integrates advanced robotic capabilities with networked connectivity and edge computing to create interconnected robotic ecosystems that can communicate, collaborate and share intelligence across distributed systems.

By bringing data processing closer to the source, edge computing significantly reduces latency, enabling robots to respond to their environments in real time, while network protocols optimized for robotic communications allow these systems to coordinate actions and share insights. This capability brings clear added value in applications where every millisecond is critical, such as autonomous driving or precision manufacturing, and brings clear added value in applications where both individual responsiveness and system-wide coordination are critical, such as autonomous vehicle fleets, warehouse automation or distributed manufacturing operations.

Edge computing combined with resilient mesh networking is transforming how robots learn, adapt and operate collectively. Integrating embedded ML directly into robotic systems while enabling secure robot-to-robot and robot-to-infrastructure communication is driving the next phase of intelligent automation, creating systems that are both individually intelligent and collectively coordinated.







Industry	Company	Outcomes
Advanced manufacturing	Gecko Robotics	Gecko Robotics' AI robotic platform enables real-time data acquisition for safer operations and smarter maintenance, reducing downtime and operational costs.
IT	NVIDIA	NVIDIA Isaac is a robotics platform that enables real-time perception, synthetic data generation and software-in-the-loop testing to speed up the development and deployment of intelligent robotic systems.

Convergence transformation

2024 marked a surge in edge computing investments.[15] As industries evolve into more sophisticated, interconnected ecosystems, omni compute is redefining how individuals and organizations interact and exchange value in the digital world. Security and trust in data infrastructure have become critical. To reduce vulnerabilities inherent in centralized systems, companies are increasingly adopting decentralized intelligent systems where data and AI are distributed across nodes. This architectural shift enhances system resilience and supports greater transparency and autonomy in data processing.

A key enabler of this momentum is the adoption of standardized protocols – such as inter-blockchain communication protocol (IBC), cross-chain message passing (XCMP), MQTT, OpenFog and IEEE 3205. These standards ensure interoperability, enhance data flow efficiency and support the seamless integration of diverse technology landscape. Technology giants are also playing a crucial role in establishing standards that shape subsequent combinations with AI and spatial intelligence. Mature omni compute technologies benefit from established protocols and pre-set rules that govern how data is transmitted and how devices communicate.

CASE STUDY 5

Qualcomm

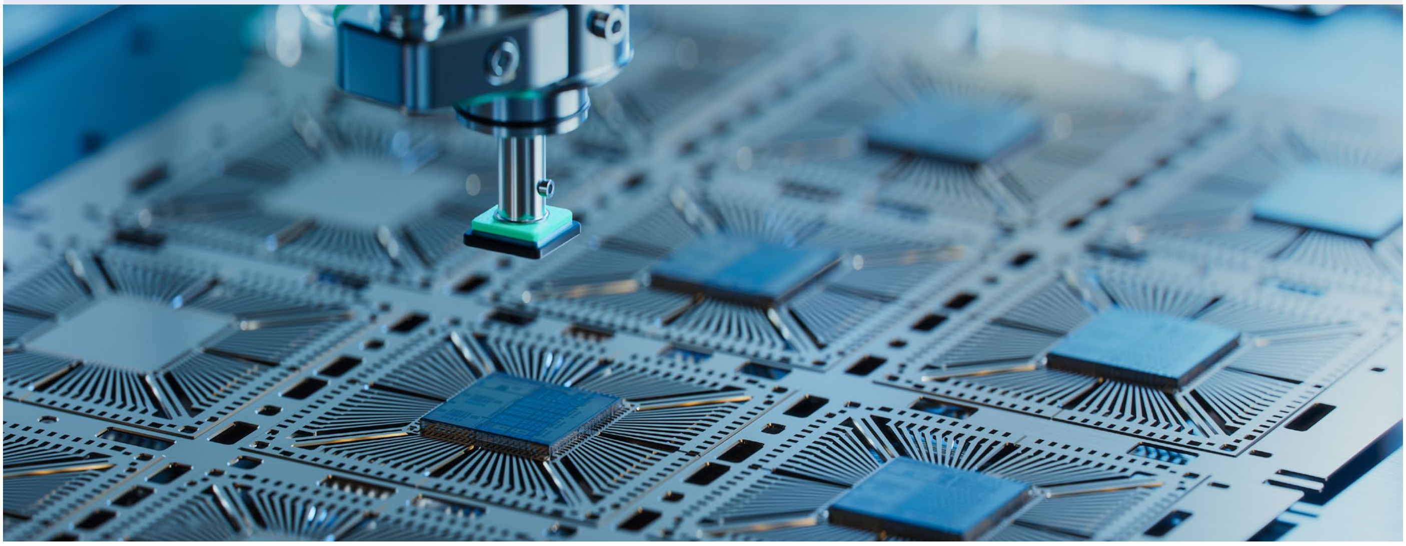
Qualcomm integrates connectivity and computing into single chips for a myriad of industry uses. The Dragonwing chip[16] powers real-time, low-latency intelligence as industries shift to AI-driven, interconnected ecosystems.

Edge robotics for logistics

The integration of Dragonwing's advanced connectivity and embedded AI-driven robotics has reshaped supply chain resilience and operational efficiency by automating tasks. This has led to cost savings and productivity gains with reduction of manual errors and optimized routes.

Real-time monitoring for smart cities

Dragonwing enables enhanced infrastructure management by supporting real-time monitoring, improving public services and safety, and providing data to inform urban planning.



On the horizon

Decentralized physical infrastructure networks (DePIN) provide another milestone to more resilient, efficient and democratic digital systems. These networks use blockchain technology to coordinate activities between distributed participants who contribute resources (computing power, storage, bandwidth or sensor data) in exchange for token incentives. DePIN today encompasses digital infrastructure such as wireless networks, computing resources, sensor networks, energy systems and transport platforms. Currently valued at $30-50 billion with over 1,500 active projects worldwide, this relatively new sector is projected to grow to $3.5 trillion by 2028, signalling its increasing importance in the broader technology landscape.

The most significant evolution within the DePIN ecosystem is the emergence of decentralized physical AI (DePAI), which marks a fundamental shift in how AI systems interact with physical infrastructure and real-world data. Unlike traditional AI development constrained by centralized data repositories controlled by large corporations, DePAI uses decentralized networks where ordinary users contribute to ML processes through everyday activities. Applications like Bittensor and Threefold demonstrate this potential, with Bittensor enabling decentralized AI model training and Threefold creating a sovereign digital identity system. Additionally, Morpheus incentivizes the first open-source peer-to-peer network for general-purpose AI, via its MOR token, and Gensyn offers an ethereum-based solution dedicated to ML, integrating off-chain execution, verification and communication frameworks. This democratization of AI training ensures models remain diverse and contextually relevant while compensating contributors through blockchain-based incentive systems. The middleware layer is rapidly maturing, with projects like IoTeX and Peaq providing critical components that bridge physical devices with blockchain networks, enabling integration and enhancing data processing capabilities and tokenomics design.

As DePIN matures, it could reshape the future of omni computing by creating a more distributed computational fabric. The primary beneficiaries include AI computing infrastructure, with the top three revenue-generating DePIN projects (Aethir, Virtuals Protocol and IO.Net) all focused on providing decentralized computing resources for AI applications. Meanwhile, the wireless connectivity sector shows promising growth, with Helium Mobile surpassing 130,000 users and growing at 5.6% monthly. As the ecosystem evolves from token-incentive models to sustainable business models driven by genuine market demand, hybrid approaches are emerging, combining traditional infrastructure with decentralized components and reshaping how computational resources are built, accessed and governed in an increasingly connected world.

2.3 Engineering biology domain

Engineering biology is transforming how biological systems integrate with physical and digital technologies, creating new capabilities across various sectors such as healthcare, manufacturing and environmental management. Advances in digital technology are further expanding the impact of engineering biology, reshaping its role in accelerating innovation.

Notably, custom-built biosensors are improving biological data collection, while product stage biocomputing and commodity stage bioinformatics are advancing computational power for understanding biological systems. Custom-built bioprinting systems are innovating the construction of complex biological structures, and metabolic engineering is reprogramming cells to produce high-value materials.

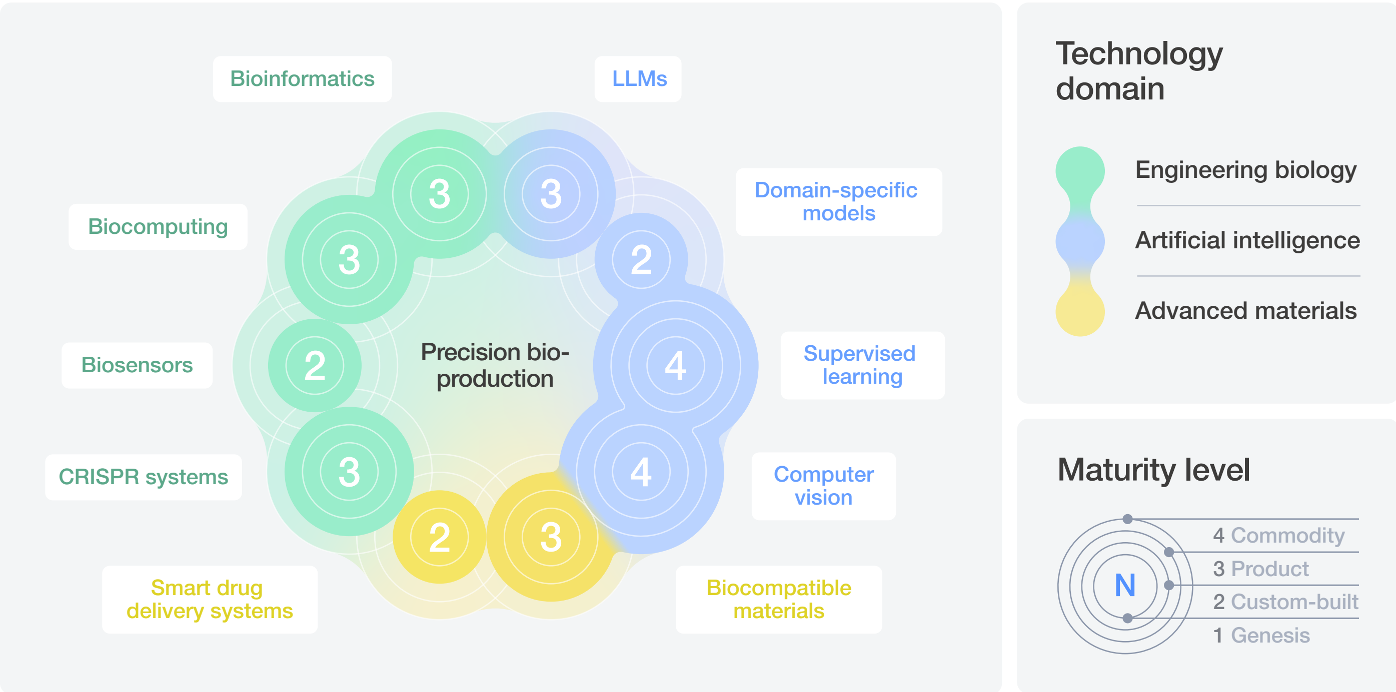
This layered maturity landscape creates the conditions for engineering biology for combinations and enables innovation. This convergence allows for integration with AI, omni compute, robotics and advanced materials.

Precision bio-production

From personalized medicine to programmable cells and food systems, precision bio-production employs engineering biology technologies, including enzyme and molecule engineering, AI-driven predictive modelling and digital twins, to create tailored materials, molecules and biological systems.

One outcome of this combination is precision biomedicine, which evolves the approach to individualized proactive diagnosis, treatment and prevention. These applications integrate patient-specific data, genomics and clinical information, with AI tools processing these multi-layered datasets to reveal how biological systems interact and influence outcomes.

Another outcome is in enzymatic and molecular-level manufacturing, where enzymes function as programmable, modular components within a dynamic bio-production stack to custom-made biomanufacturing products. What makes this combination particularly powerful is its ability to create self-sustaining, adaptive bio products that can evolve and respond to changing environmental conditions.

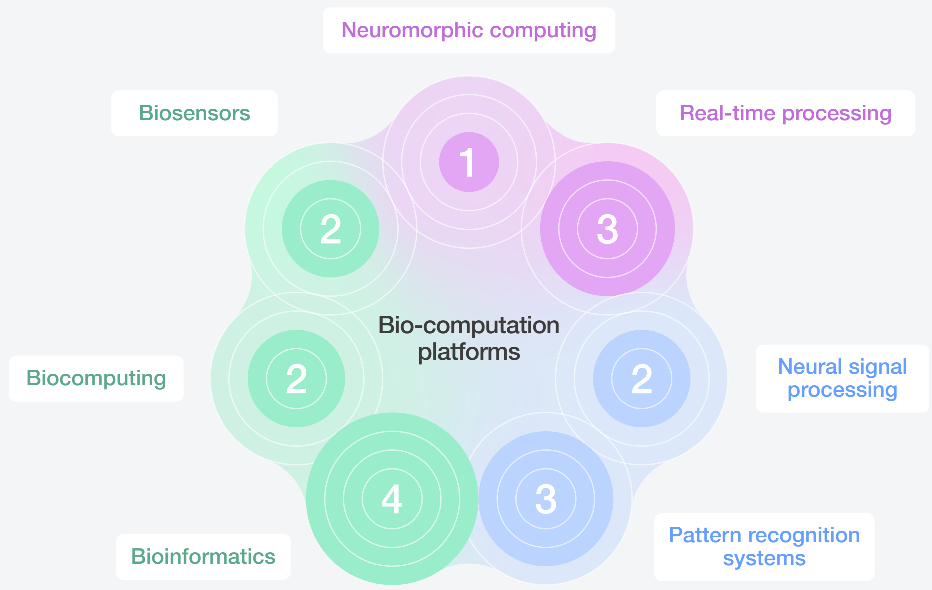


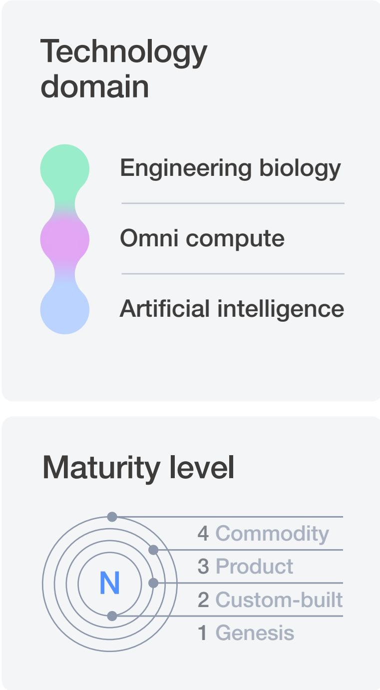
This combination highlights how precision bio-systems are transforming the delivery of engineering biology solutions, making them increasingly personalized and tailored to specific needs. These advancements cut across industry value chains, from healthcare to agriculture and energy.

Industry	Company	Outcomes
Healthcare	Merck	AI-driven drug formulation enables personalized treatments, scaling research, analyzing unprecedented data and improving the health of every patient.
Agriculture	DSM-Firmenich	DSM-Firmenich uses their AI platform to optimize microbial culture innovation for improved crop resilience and an expanded product offering.
Energy	Cemvita	Synthetic biology produces biofuel for low-carbon feedstock creation, streamlined processing and an accelerated energy transition towards a carbon-neutral future.

Bio-computation platforms

Bio-computation platforms represent a breakthrough at the intersection of biology and computation, where biology is not just observed but used to compute, mimicking certain functional, structural and physiological aspects of the human brain. This biological computation interfaces are still nascent but represent a foundational convergence frontier as they are pushing forward direct, bidirectional communication channels between living tissue and electronic systems. The sophistication of these interfaces is enabling unprecedented applications in both medical treatment and human-computer interaction.



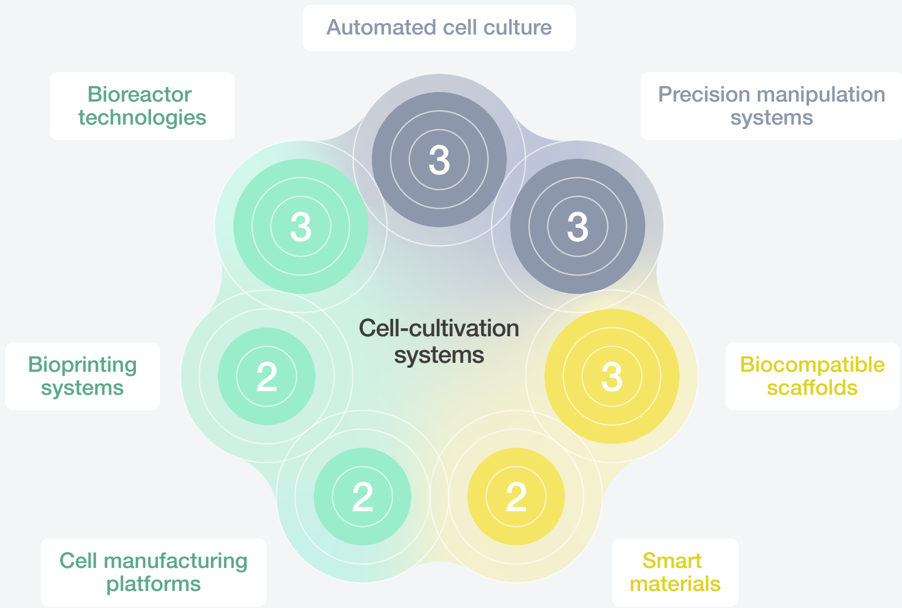


The power of this convergence lies in its ability to translate complex biological signals into a computational format that can be processed and acted upon in real time. This combination enables stakeholders to expand their footprint across the computing industry value chain.

Industry	Company	Outcomes
IT	Catalog	DNA-based data platforms enable ultra-dense, durable, and energy-efficient storage and computation for long-term digital information management.
Healthcare	Cortical Labs	Biological-silicon computing develops faster-learning, more adaptive AI systems and unlock new capabilities in cognitive automation.

Cell-cultivation systems

By combining biological production methods with advanced manufacturing technologies, a new generation of scalable and precise cell-cultivation systems is emerging. This convergence addresses a long-standing challenge: bridging the gap between laboratory-scale biological processes and industrial-scale biomaterials. Advanced engineered organisms and fermentation are transforming the production of materials, compounds and nutrients. The integration of bioreactors, bioprinting systems, AI-optimized culture conditions, robotics and automated cell systems is laying the foundation for more efficient, resilient and sustainable bioproduction.



Technology domain

- Engineering biology
- Robotics
- Advanced materials

Maturity level

Industry	Company	Outcome
Healthcare	Regeneron	Cell culture bioreactors scale the production of biologics, accelerating drug development and supporting industrial-scale biopharmaceutical manufacturing.
Textile	AMSilk	Protein-based biofibres enable sustainable, high-resistance, lightweight materials for use across textiles, biomedical devices and automotive applications.

Convergence transformation

The combination patterns in engineering biology demonstrate how biological and digital systems are becoming increasingly intertwined, creating transformative capabilities that extend far beyond traditional applications. These combinations, empowered by advancements in AI, have significantly accelerated the value chain transformation into new product categories and can now address previously unsolvable challenges. Traditionally, engineering biology technologies operated mainly in the healthcare industry, with long go-to-market strategies due to extensive research and development as well as certifications. Now, with recent breakthroughs in AI, it is transforming the value chain by enabling engineering biology to learn from data, recognize patterns, and be much more precise and tailored to complex environments, creating new applications in consumer goods, energy and the food industry.

As engineering biology technologies continue to mature, investors remain optimistic about the potential of start-ups in this field.[17] Venture investment appears to have stabilized at levels seen prior to the COVID-19 pandemic-era spike. However, due to the inherent technological complexity, high capital requirements and extended go-to-market timelines, capturing investor interest remains challenging. As narratives increasingly shift towards planetary outcomes, application areas beyond healthcare are expected to become more attractive for investment.

The cross-cutting and technologically complex nature of the engineering biology technology poses significant barriers in devising comprehensive yet efficient policy and regulatory frameworks. Early policy decisions are especially influential, as they shape the speed and scale at which bio-based, tech-driven approaches can be adopted. Momentum varies widely across regions, influenced by national priorities, regulatory readiness and the ability to integrate bio-based innovation into broader industrial strategies.

CASE STUDY 6

The Commonwealth Scientific and Industrial Research Organisation (CSIRO)

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has embraced application and development of AI for scientific research, incorporating advanced ML capabilities directly into its scientific workflows. By integrating AI specialists into multidisciplinary research teams, CSIRO enhances its ability to achieve precise molecular design, optimize complex biological processes and perform real-time experimentation across various scientific disciplines.

These initiatives accelerate research, enabling rapid simulation and iterative development. They reinforce CSIRO's leadership in engineering biology and enhance its capacity to address complex challenges across healthcare, agriculture and energy sectors. This approach creates a continuous feedback loop of innovation, significantly amplifying CSIRO's cross-industry impact.

AI for plant protein

AI-driven biological modelling to optimize crop resilience, improve yields and reduce environmental impact. By predicting yield, taste and functional properties of different plant proteins, they accelerate new ingredient and product development, reducing time-to-market while promoting innovation.

Precision fermentation for food innovation

CSIRO uses precision fermentation to engineer microorganisms that produce animal-free proteins and fats. This enables the development of lactose-free, sustainable dairy alternatives, meeting growing consumer demand, unlocking potential new market segments.

On the horizon

Engineering biology is at a transformative inflection point, driven by a convergence of technological breakthroughs that extend its impact well beyond traditional healthcare. The synergy between AI and the explosion of biological data is reshaping the speed, cost and possibilities of biological engineering, shortening discovery timelines, broadening access to advanced techniques and enabling the precise manipulation of increasingly complex biological systems.

In the near term, bio-manufacturing is poised to become the standard production method for an expanding range of products – from pharmaceuticals and specialty chemicals to novel materials and consumer goods. As bioinspired materials and advanced biomechanics merge with automation technologies, manufacturing processes that uses biological systems will become economically competitive with traditional methods while offering superior sustainability profiles. Companies across sectors are already incorporating enzymatic processes, cell-free systems and microbial bioreactors, driven by both cost benefits and regulatory pressure for sustainable practices. Simultaneously, emerging combinations like organoids and brain-on-chip technologies are creating sophisticated testing platforms that better predict biological responses and accelerate innovation cycles while reducing dependence on animal testing.

Looking further ahead, large-scale engineered biological systems are expected to play a key role in environmental management and resource generation. Though synthetic ecosystem technologies remain largely at the genesis stage, they show tremendous promise for applications ranging from carbon capture and bioremediation to sustainable agriculture and resource extraction. The maturation of supporting technologies – particularly in monitoring, modelling and control systems – is laying the essential foundation for these more ambitious applications. Realizing the full potential of engineering biology will require coordinated efforts across industry, academia, regulatory bodies and public stakeholders to overcome technical hurdles, establish oversight frameworks and ensure equitable access. Organizations that successfully navigate this complex landscape will find opportunities to expand into entirely new markets, create sustainable competitive advantages and contribute to solving some of humanity's most pressing challenges.

2.4 Spatial intelligence domain

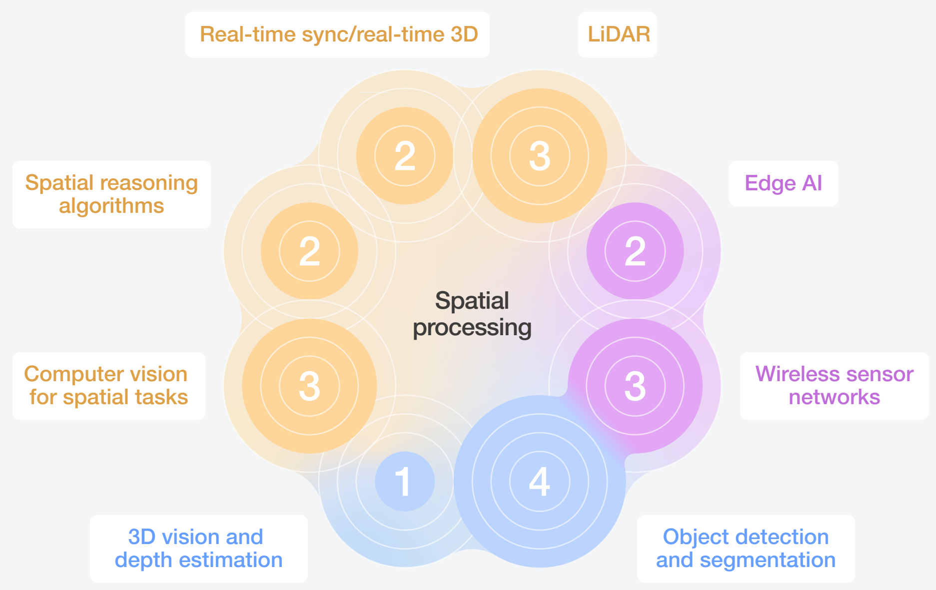
Spatial intelligence represents a fundamental shift in how physical environments are perceived, analysed and interacted with. It is transforming the understanding of and interaction with physical space, enabling collaboration, simulation, operation and ultimately not only monitoring but also simulating physical assets from virtual environments.

At the cutting edge of innovation, custom-built technologies such as physical-digital integration, mixed reality platforms and digital twin technology are driving advancements in immersive space, spatial simulation and interaction. At the same time, technologies such as computer vision, LiDAR and spatial analytics provide 3D data and spatial environment context required for interoperability and large-scale applications.

As these technologies continue to evolve and intertwine, they are opening substantial opportunities in novel business models and customer engagement and creating value across industries.

Spatial processing

This pattern is changing how systems perceive, analyse and interact with 3D environments. The pattern integrates multiple precision technologies shown in the diagram: high-resolution LiDAR systems that capture millimetre-precise spatial data; 3D vision and depth estimation techniques that create dimensional understanding; edge analytics that process spatial data directly at capture points; and object detection and segmentation that identifies and categorizes elements within spatial information with minimal latency. Applications being seen include urban planning, where computer vision is being used for spatial tasks alongside wireless sensor networks to create comprehensive spatial models that accurately simulate urban phenomena. In manufacturing, spatial processing combines physical-digital integration with real-time sync capabilities to achieve precise alignment for robotic systems and augmented reality overlays for inspectors, significantly improving efficiency. Advanced medical applications bring together object detection techniques with 3D vision systems to enhance surgical precision while maintaining the critical low latency needed for real-time guidance.



Technology domain

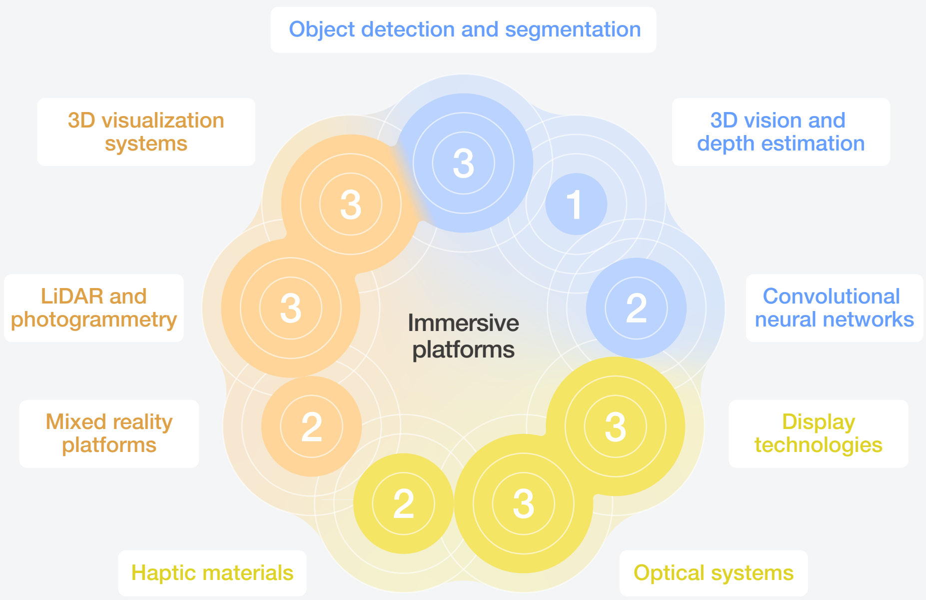
- Spatial intelligence
- Omni compute
- Artificial intelligence

Maturity level

Industry	Company	Outcomes
Healthcare	Synchron	Neural interface technology enables the seamless integration of spatial data, facilitating intuitive human-machine interaction, enhanced accessibility and improved quality of life.
Smart cities	Hayden AI	AI-powered traffic enforcement enables efficient urban mobility, reduced congestion and improved safety for public transit systems and commuters.

Immersive platforms

By combining mixed reality platforms, spatial computing engines and advanced computer vision systems, these platforms create environments where digital content feels naturally integrated within the physical world. The technical foundation includes precise spatial awareness capabilities, with technologies that can map environments at 30 frames per second and anchor 3D holograms with millimetre precision. This integration is enhanced by convolutional neural networks for object recognition, 3D-vision systems for depth estimation and advanced display technologies that render digital information seamlessly within the user's field of view.



Technology domain

Spatial intelligence

Artificial intelligence

Advanced materials

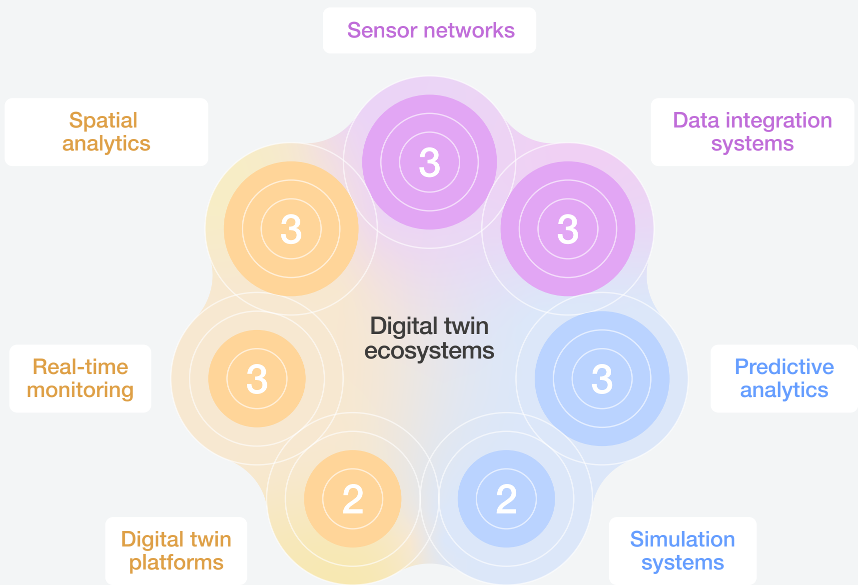
Maturity level

Industry	Company	Outcomes
Gaming	XREAL	Mixed reality glasses enhance immersive gaming and experiences, create new revenue opportunities and drive higher customer engagement.
Training	TeslaSuit	A haptic wearable suit that improves training effectiveness, enhances user performance and enables immersive experiences across enterprise, gaming and sports applications.

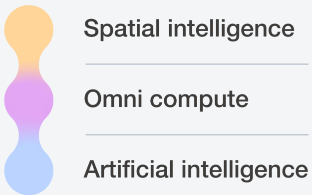
Application is being seen in aerospace manufacturing, where companies have reduced assembly errors by implementing mixed reality-guided workflows that align computer-aided design (CAD) models with physical components. Medical training has been revolutionized through virtual simulations incorporating haptic feedback, improving procedural accuracy for complex interventions. These applications demonstrate how immersive platforms are creating intuitive interfaces where virtual information appears precisely where needed, enabling digital content to be experienced in ways that feel natural and contextually relevant.

Digital twin ecosystems

Digital twin ecosystems represent a combination of IoT sensor networks, physics-based simulation engines and AI/ML-driven predictive analytics that create dynamic, intelligent replicas of physical systems. For instance, gas turbine original equipment manufacturers' (OEMs) maintenance systems can now combine continuous IoT sensor data (tracking vibration, temperature and pressure) with finite element analysis simulations to predict component fatigue before failure, reducing unplanned breakdowns.[18] Similarly, auto OEMs are implementing factory-wide digital twins that synchronize robotic arm telemetry with discrete event simulation models, cutting production planning time[19] while improving throughput. The power of these ecosystems stems from their closed-loop interoperability – real-time spatial data continuously updates simulation engines while AI analyses simulation outputs to prescribe optimizations that can be executed automatically through industrial control systems or presented to human operators for approval. As these ecosystems mature, they're evolving into interconnected system-of-systems networks – essentially an "internet of twins" where digital replicas share insights and optimizations across organizational boundaries.



Technology domain



Maturity level

Industry	Company	Outcomes
Aerospace	Blackshark.ai	Geospatial digital twins drive operational efficiency, reduce infrastructure costs, accelerate scenario planning and enhance strategic decision-making through accurate, real-world spatial insights.
Healthcare	Twin Health	Digital twin technology enables personalized treatment, improves patient outcomes and reduces healthcare costs by proactively reversing chronic metabolic diseases.

Convergence transformation

The convergence of spatial intelligence and immersive technologies is fundamentally transforming the perception, interaction with and optimization of physical spaces. Initial investments in spatial intelligence technologies were driven by advancements in virtual reality (VR) and augmented reality (AR), now significant investments are being directed towards hardware innovations (such as advanced sensors and haptic feedback) and AI-driven software platforms that enhance user experiences and expand the functionality of immersive technologies.

Efforts are under way to standardize tools and methods in spatial intelligence and computer vision to enhance interoperability, accuracy and efficiency. In the area of object recognition, standards have been widely adopted for their accuracy and speed in identifying and classifying objects in real-time. For VR, the use of game engines such as Unity and Unreal Engine has become a standard practice, providing consistent development environments and support.

CASE STUDY 7

Siemens – digital twin

At the heart of this transformation towards increasing energy efficiency, speeding up product development, reducing waste and building more resilient systems is the digital twin: not just a virtual representation of an asset, but a dynamic system that connects physical and digital worlds in real time.

As these systems evolve, the next great enabler is the emergence of AI agents. They not only interpret data across isolated platforms but also connect insight to action through software-defined automation – making industrial systems more adaptive, predictive and efficient.

Together with partners like NVIDIA, Amazon Web Services (AWS) and Sony, Siemens is embedding these capabilities into immersive, physics-based environments where products, production lines and infrastructure can be simulated and tested with real-world precision. Whether it's reconfiguring a factory, optimizing a city district or designing a next-gen aircraft, the industrial metaverse is emerging as an ecosystem of interoperable digital twins.

Immersive product design for aerospace

Natilus uses Siemens' immersive design tools to bring full-scale aircraft models into collaborative XR environments. This allows engineers and stakeholders to interact with complex systems in real time, improving team alignment and speeding up design cycles.

Factory digital twin for food and beverage

Heineken uses Siemens' digital energy twins to simulate energy use across breweries and identify major opportunities for decarbonization. With 15-20% energy savings and up to 50% CO_2 reduction per site, the solution is now being scaled globally.

Digital systems for urban infrastructure

Siemensstadt Square in Berlin is being reimagined and developed with a digital twin ecosystem that integrates building, energy and campus-level twins. This end-to-end digital backbone helps identify challenges early, supports collaborative planning and accelerates smart decision-making.

On the horizon

Spatial intelligence technologies are unlocking new levels of immersion and are already being adopted across multiple industries. This momentum is producing compounding network effects, including a surge in demand for spatial computing skills, the emergence of new interoperability standards, and economies of scale in hardware and software ecosystems.

As spatial intelligence convergence matures, new waves of innovation will emerge such as real time 3D systems,[20] the combination of omni compute, AI and robotic advanced sensors and motion capture technologies in any environments. Industries such as healthcare develop reactive "human digital twins" in real time – virtual representations of patient-specific anatomy and physiology. These real-time 3D systems will reshape how surgeries are planned and enhance global collaboration among healthcare experts.[21] In the entertainment industry, real-time 3D systems with volumetric sensors will enable live mixed-reality concerts and audience-personalized content, expanding the role of audience from passive to active participants, creating new forms of engagement, monetization and creative expression.

2.5 Robotics domain

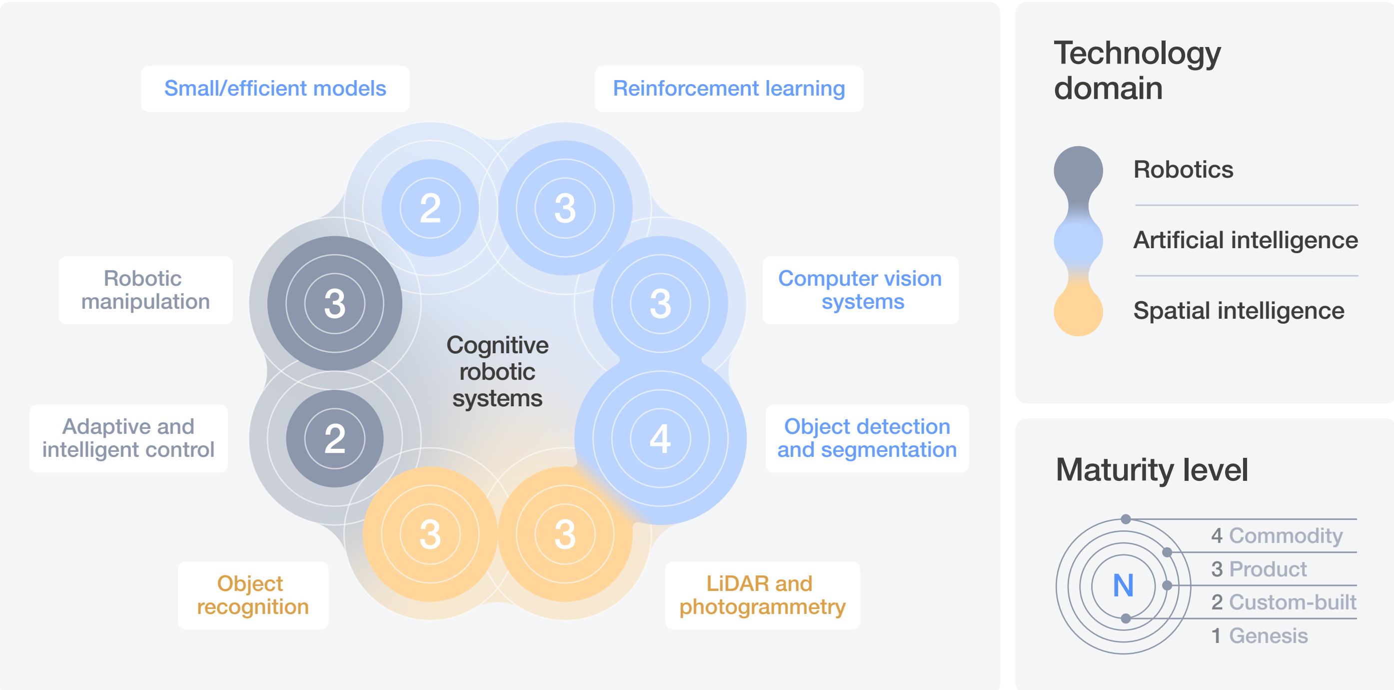
Falling prices of robotics hardware components, a burgeoning ecosystem with new entrants and increasing global competition are making the field of robotics advance at unprecedented speed.

Breakthroughs in adaptive control and biomimetic actuators are enhancing robotic flexibility and precision, while soft robotics improves delicate handling and multi-robot coordination boosts autonomous collaboration in dynamic environments. Meanwhile, established technologies like robotic manipulation, gesture recognition, motion planning, tactile sensors and robot-to-robot communication ensure reliability for large-scale deployment. Robotic manipulation allows precise tasks, motion planning optimizes navigation with autonomous vehicles and drones benefiting from these advancements.

Cognitive robotics systems

Cognitive robotics systems combine multi-modal sensor fusion, adaptive ML architectures, and real-time control optimization to create machines that genuinely understand and respond to their environments. This evolution moves robotics beyond pre-programmed routines towards contextual awareness and adaptive intelligence. Advanced vision-language models (VLMs) and 3D spatial AI now fuse data from LiDAR, cameras and inertial sensors to reduce environmental mapping errors. These perception advances are evident in practical applications such as integrating geometric and semantic understanding to allow robots to dynamically adjust paths in warehouses with fewer false positives in obstacle detection and pick-and-place tasks with higher efficiency.

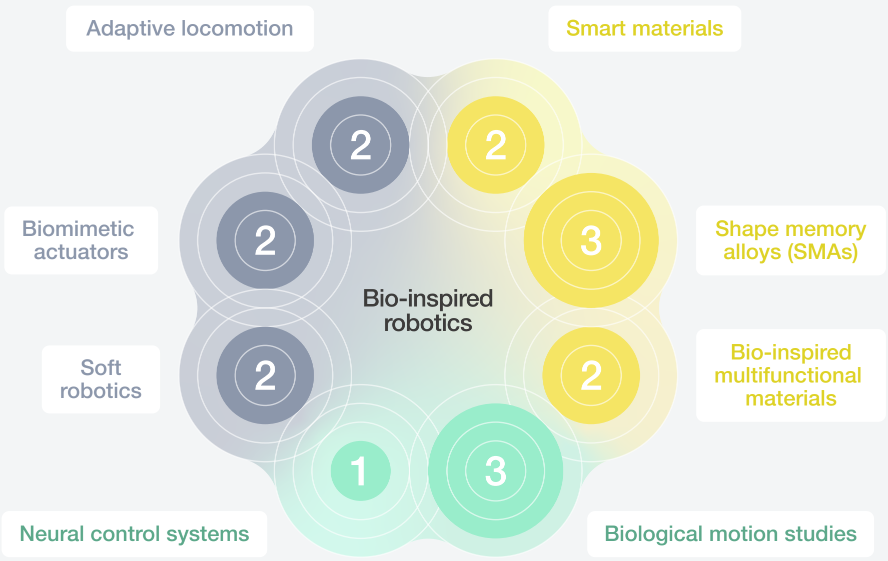
The impact of cognitive robotics extends across multiple domains through edge-based federated learning systems enable distributed robots to collaboratively refine their models without sharing sensitive data, reducing cloud dependency energy costs. In autonomous vehicles, the integration of radar and camera inputs with model predictive control has cut emergency braking response times. Industrial applications are equally transformative, with cognitive control frameworks using supervisory attentional systems to let robots switch tasks faster when human collaborators intervene.



Industry	Company	Outcomes
Automotive	Waabi	An autonomous trucking platform that offers scalable, safe, and adaptable solutions to improve efficiency and reduce operational costs.
Manufacturing and supply chain industry	NEURA Robotics	Cognitive robots increase productivity, reduce operational costs and enhance safety by automating workflows and enabling seamless human-robot collaboration.

Bio-inspired robotics

Bio-inspired robotics is a design paradigm that combines advanced materials, neuromorphic control systems and biomechanical engineering to create machines that outperform conventional rigid robots in adaptability and efficiency. This combination pattern integrates four key technological synergies: first, material and actuator systems like gecko-inspired climbing robots employ nano-structured dry adhesives paired with shape-memory alloy actuators. This achieves adhesion efficiency while sustaining shear forces – enabling industrial inspections in hazardous environments. Second, sensor and control architectures allow robotic fish to use pressure-sensitive lateral line sensors and biomimetic sonar arrays coupled with shunting neurodynamic models based on biological neural networks, achieving real-time obstacle avoidance response rates and reducing collision risks in coral reef monitoring tasks. Collectively, these bio-inspired systems are demonstrating three- to five-times greater improvements in energy efficiency, adaptability and task specialization compared to traditional robotics approaches, converting evolutionary constraints like energy scarcity and environmental unpredictability into engineering strengths.



Technology domain

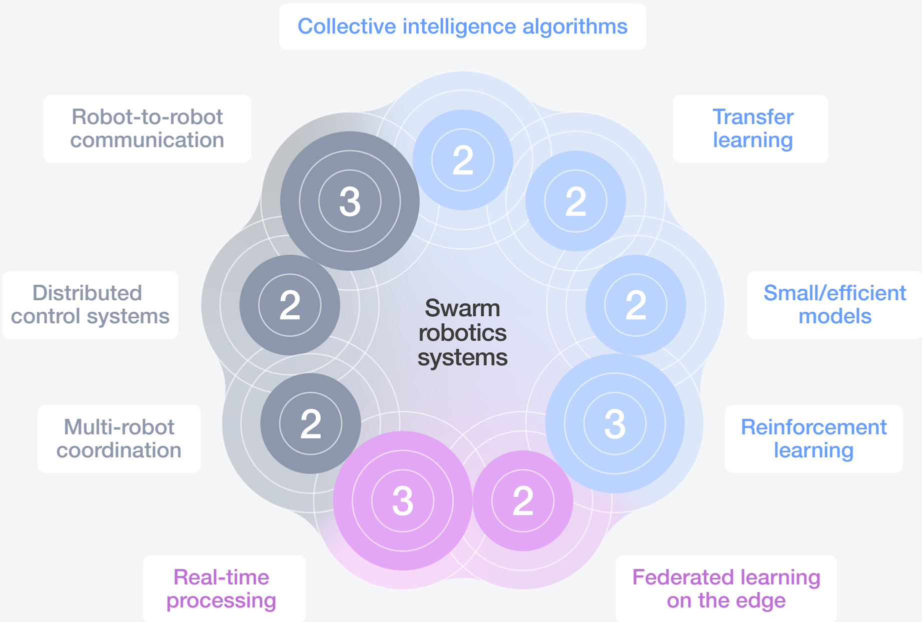
- Robotics
- Advanced materials
- Engineering biology

Maturity level

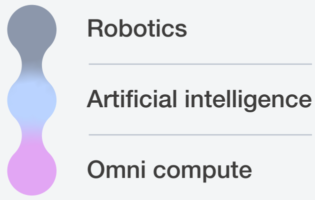
Industry	Company	Outcomes
Manufacturing and consumer goods	Figure AI	Humanoid robots support workforce productivity while reducing operational costs, and improve versatility by combining human-like dexterity with advanced AI capabilities across multiple sectors.
Healthcare industry	Angel Robotics	Angel Robotics provides real-time, sensor-free movement analysis, improving rehabilitation and daily life support through advanced biomechanics.

Swarm robotics systems

Swarm robotic systems reimagine robot coordination through collective intelligence rather than individual complexity. Drawing inspiration from biological systems like ant colonies or beehives, relatively simple individual agents following basic rules can collectively perform remarkably sophisticated tasks through their interactions. Swarm robotics distributes capabilities across numerous simpler robots that communicate and coordinate their actions. This decentralized architecture creates systems with emergent intelligence, demonstrating measurable advantages in resilience and efficiency.



Technology domain



Maturity level

Industry	Company	Outcomes
Aerospace	NASA[22]	Using stigmergy, NASA's PUFFER rover swarms achieve higher obstacle avoidance success than solo rovers.
Manufacturing and supply chain industry	UBTech[23]	UBTech's swarm humanoid robot framework boosts productivity, streamlines workflows and reduces operational costs by enabling autonomous collaboration and scalable automation.

Convergence transformation

The global robotics market is poised for substantial growth, driven by the need for task automation, efficiency gains and real-time autonomous decisions. Investments are increasingly targeting intelligent, adaptable systems and recent investments are focused on developing dedicated hardware and software that simulate real-world environments. This physical AI approach enables robots to train in virtual environments and learn from experience rather than traditional programming. Investment in collaborative robotics is also increasing,[24] showing that investors are looking for versatile robots capable of handling multiple tasks and working together autonomously.

As robotics systems integrate multiple technologies, managing their increasing complexity becomes a significant challenge. The rapid evolution of these systems underscores the need for robust standardization frameworks to ensure safety, performance and interoperability. Establishing safety protocols for human-robot collaboration will mitigate risks and facilitate interaction. Defining performance metrics for adaptive and AI-driven systems will help assess reliability and efficiency. Ensuring interoperability between different robotic platforms is crucial for integration across industries. A comprehensive approach to standardization will contribute to the reliable and scalable deployment of robotics in diverse applications.

CASE STUDY 8

Boston Dynamics – cognitive robots

Boston Dynamics is a native technology convergence company integrating robotics, AI, real-time processing and sensor integration to develop scalable robotic solutions capable of navigating dynamic environments.

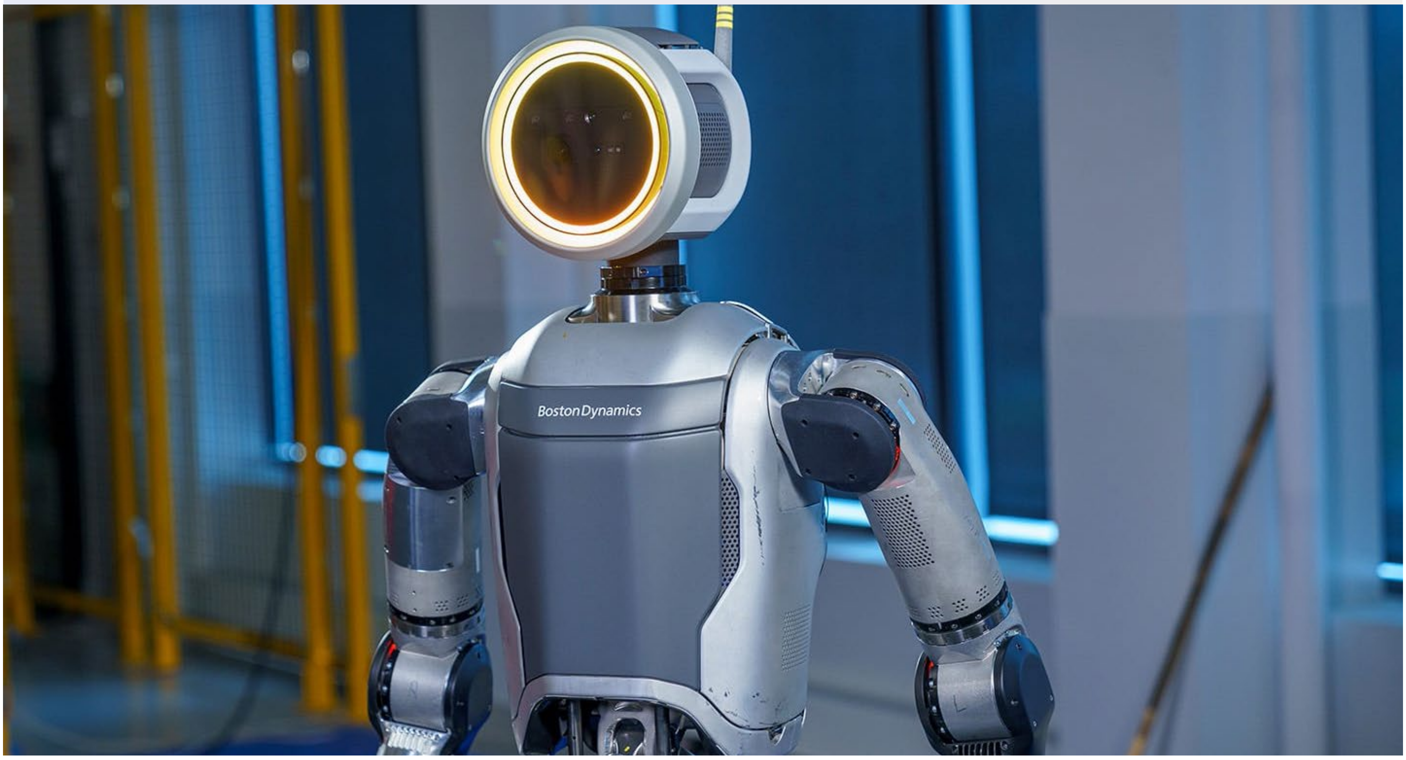
The humanoid form of Boston Dynamics' latest robot, Atlas, is particularly advantageous, enabling it to operate seamlessly in environments specifically designed for humans. These advanced capabilities extend beyond the company's defence origins, enabling Boston Dynamics to automate both routine and hazardous tasks. Through technology convergence, Boston Dynamics continues to expand its value chain and redefine automation across multiple sectors.

Cognitive robot for autonomous maintenance

AB InBev uses Boston Dynamics' Spot robot for a predictive maintenance programme in their breweries. This has led to a significant reduction in production downtime, optimized energy use and delivered a ROI demonstrating measurable impact on operational performance and cost efficiency.

Automate handling for warehouse solutions

DHL Supply Chain is collaborating with Boston Dynamics' Stretch to automate trailer unloading. This flexible, easily integrated solution increases the flow of goods and improve associate safety by taking over physically demanding tasks.

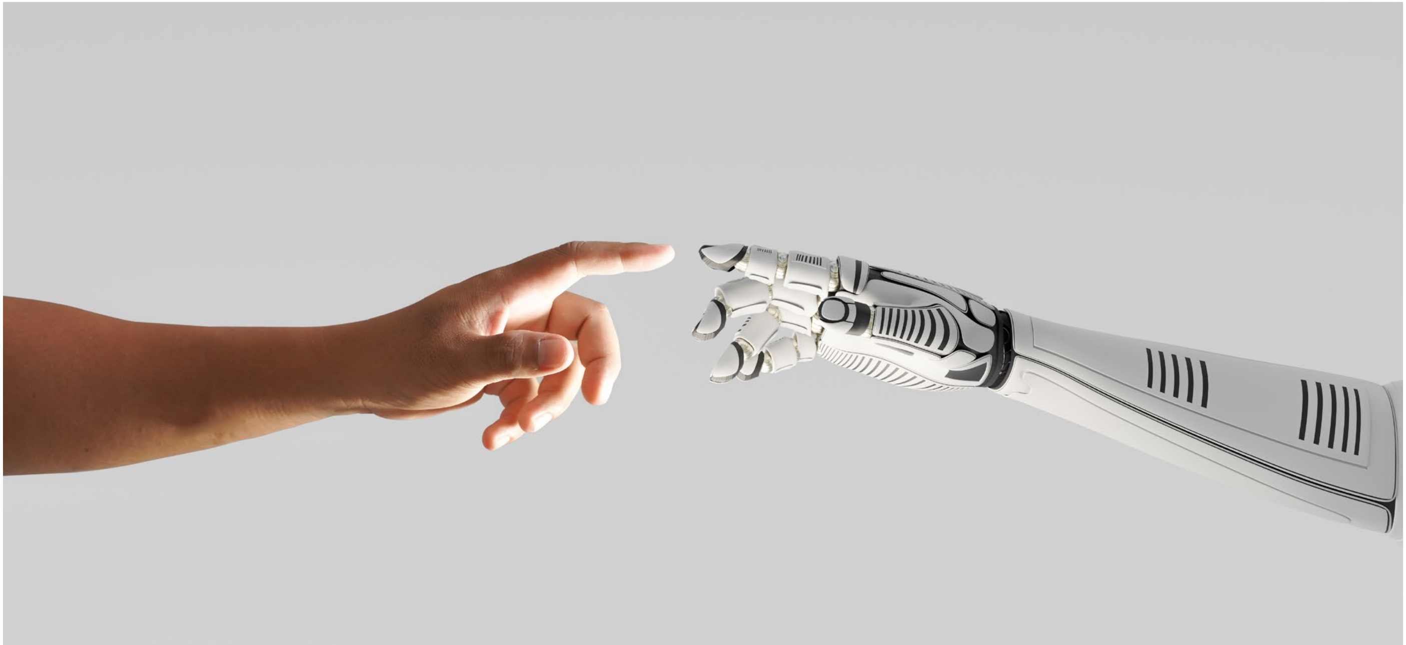


On the horizon

The robotics ecosystem is advancing with physical AI, featuring humanoid robots like Figure's Figure 01, Unitree's G1/H1 and Boston Dynamics' Atlas. These robots combine AI with whole-body control systems to navigate human environments and perform dexterous tasks. Autonomous drones are also evolving into adaptive swarms capable of independent navigation and complex missions even without GPS.

A major challenge in physical AI development is data scarcity, unlike language models that have vast datasets. This is being addressed through simulation platforms like NVIDIA's Omniverse and Isaac Sim, where robots learn in virtual worlds before applying skills in reality. These simulations include synthetic data generation, multi-agent interaction and photorealistic rendering, enhancing robots' learning and adaptability. Integrating LLMs allows natural language instruction and semantic understanding, lowering the entry barrier into robotics and enabling rapid design iteration.

The future of robotics involves developing foundation models for general-purpose capabilities across various platforms, similar to LLMs in language processing. Companies like Physical Intelligence and Skild AI are creating these models by training on diverse datasets from simulations and real-world interactions. These models will enable robots to generalize from prior experiences, reducing deployment time and engineering effort. The cost of building humanoid robots is expected to drop significantly, from approximately $35,000 in 2025 to around $17,000 by 2030.[25] This reduction is driven by advancements in component design, economies of scale, and cost-effective materials and manufacturing techniques. As costs decrease, robot adoption will accelerate, enabling businesses to automate tasks in manufacturing, logistics, healthcare and agriculture, facilitating innovation and efficiency at scale.



2.6 Advanced materials domain

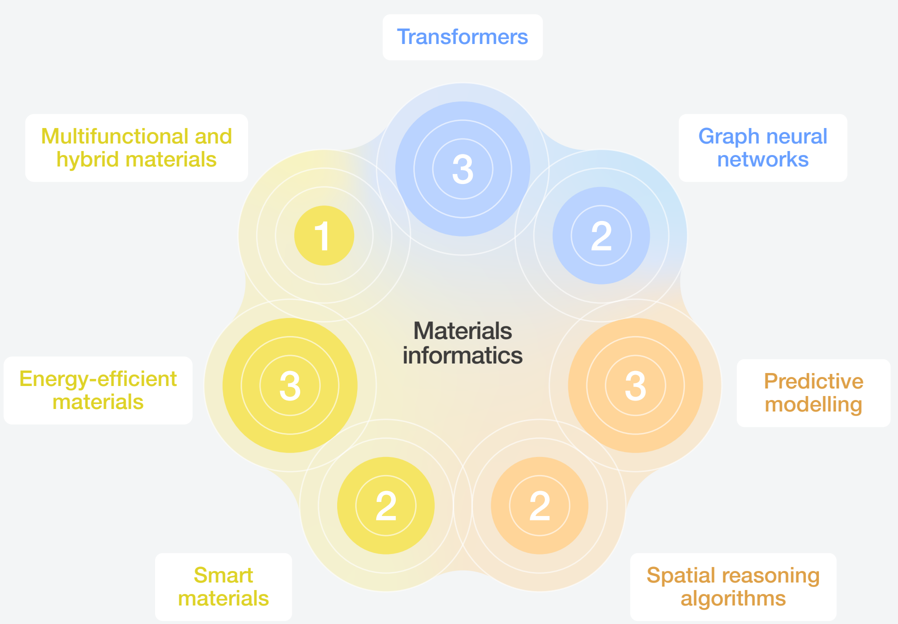
Progress in advanced materials is fundamentally transforming how technological solutions are designed, manufactured and implemented across industries. This technology domain encompasses a diverse range of advanced materials, meticulously engineered to meet the evolving needs of various industries. These materials stand out due to their enhanced properties and functionalities, enabling novel applications and convergence with other technology domain, driving improvements in performance, sustainability and efficiency in novel applications. The integration of AI has further unlocked new avenues for developing innovative materials, expanding possibilities across a wide array of industries and use cases.

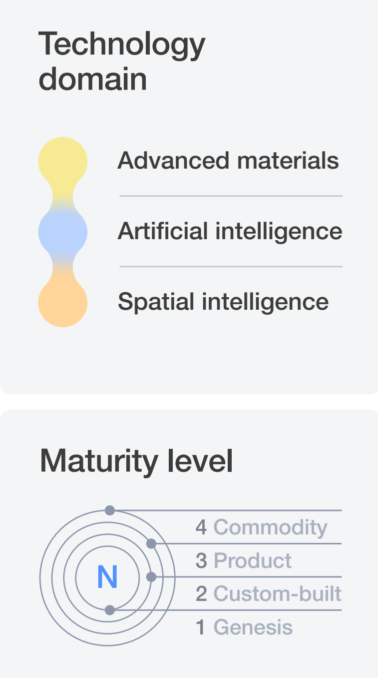
New developments in self-healing materials and biofabricated materials are enhancing adaptability and sustainability, while thermoelectric materials are optimizing energy efficiency in various applications. Meanwhile, established technologies such as energy storage materials are improving battery performance and longevity, piezoelectric materials are enabling energy harvesting and advanced sensing capabilities, and biocompatible implants are revolutionizing medical treatments.

Materials informatics

By merging computational simulation with experimental insights, this modelling approach creates dynamic models that continuously learn and evolve as they incorporate new data. Unlike traditional methods that rely heavily on physical trial-and-error, adaptive modelling enables scientists to explore virtual-material combinations and structures before synthesizing them in a laboratory. The power of this approach lies in its ability to accelerate innovation cycles – what once took years of incremental testing can now be accomplished in months through predictive algorithms that identify promising candidates with specific properties. This convergence of disciplines enables researchers to simulate material behaviours across multiple scales simultaneously, from quantum interactions at the atomic level to macroscopic mechanical properties, creating a comprehensive understanding that bridges theoretical and practical applications.

Aerospace manufacturers use these technologies to design lightweight composites with enhanced thermal resistance and structural integrity, significantly reducing development cycles while improving safety margins. Energy storage solutions have evolved through models that predict electrolyte stability and ionic conductivity, leading to batteries with higher capacity and extended operational lifespans. In healthcare, adaptive modelling has revolutionized biomaterials development, creating substances with precisely controlled degradation rates for tissue engineering and drug delivery systems. Beyond accelerating innovation, this approach substantially improves sustainability by minimizing material waste during the development process – virtual testing replaces countless physical prototypes, reducing environmental impact while maximizing resource efficiency.

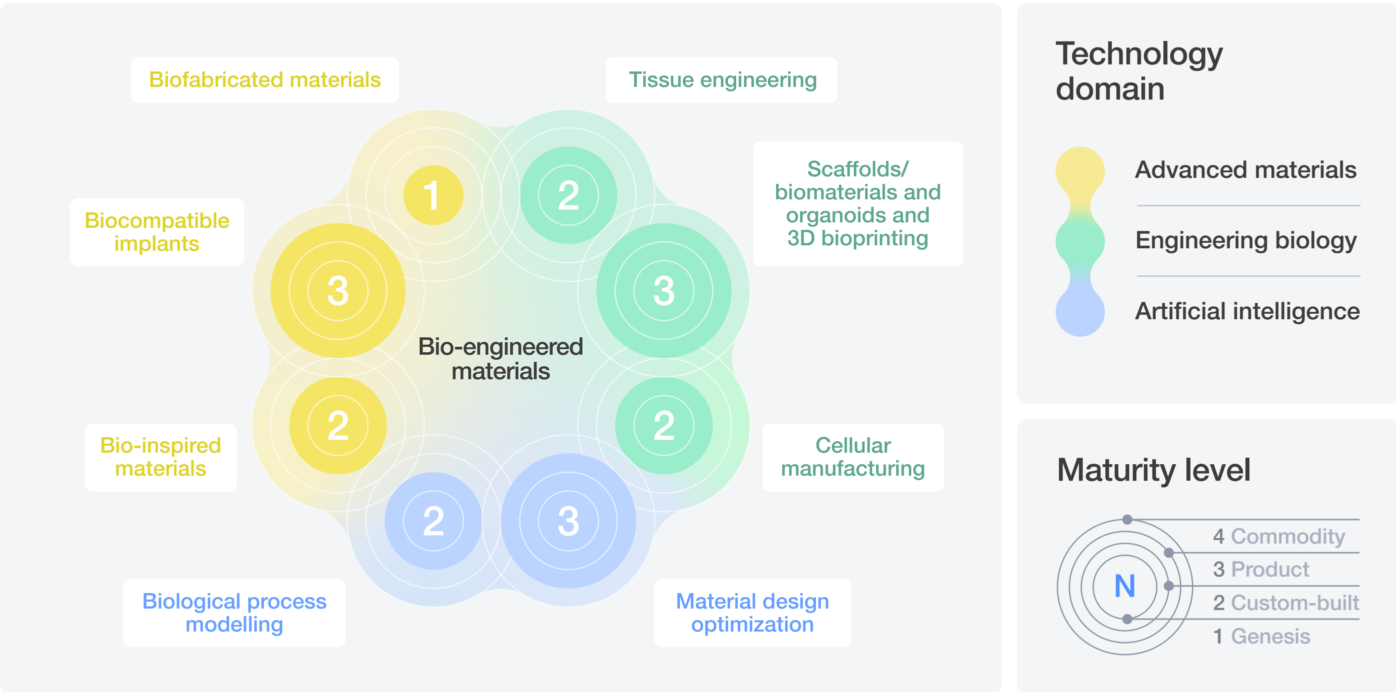




Industry	Company	Outcomes
Advanced manufacturing	Hexagon	3D material modelling brings operational efficiency, reduces costs and improves decision-making by providing real-time data.
Chemistry industry	Kebotix	A platform-as-a-service for predictive modelling accelerates material discovery, reduce R&D costs, optimize material properties and drive sustainable innovation.

Bio-engineered materials

This technological combination enables the embedding of biological logic and functionality into engineered frameworks, moving beyond biomimicry towards truly hybrid materials. Natural materials demonstrate remarkable properties, but bioengineered materials amplify these through recombinant proteins and engineered structures. These materials can be game-changers in the sustainability sector to create bio-fuel, bio-based chemicals, and support the recycling process, i.e. all aspects of the circular economy.

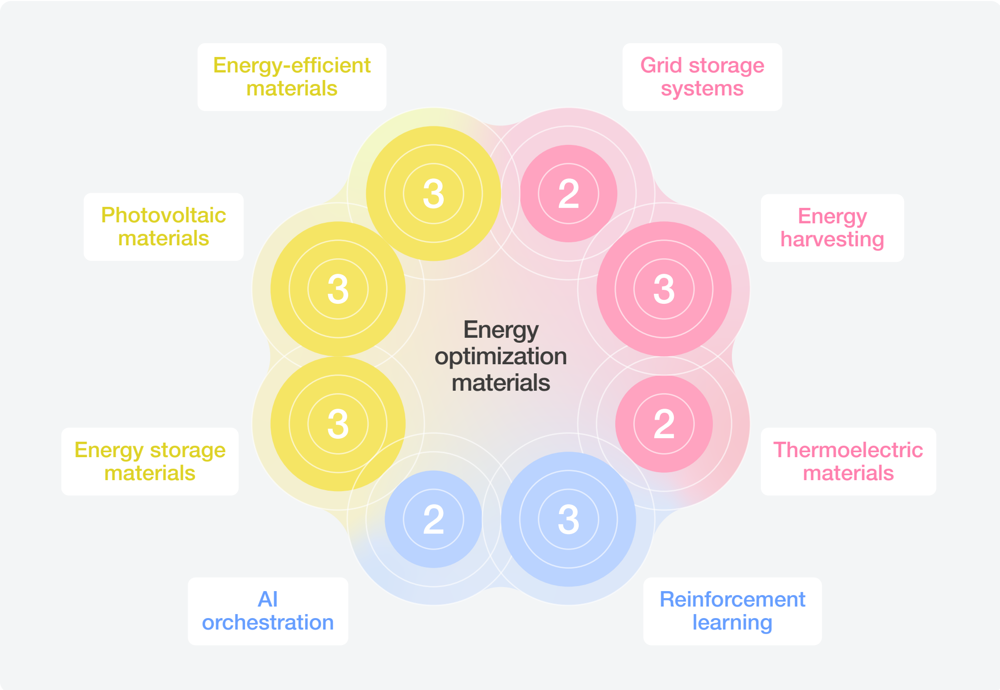


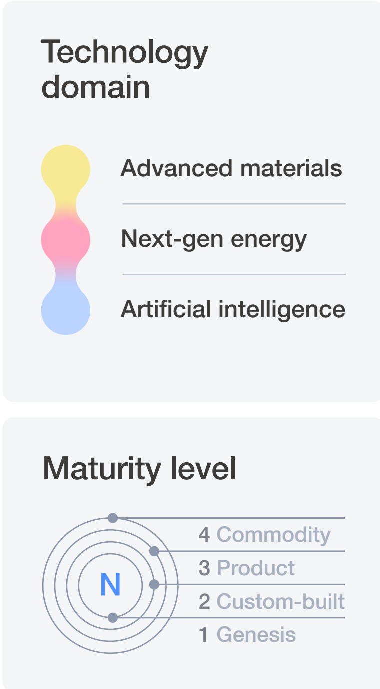
What makes this pattern transformative is its ability to resolve material trade-offs, combining high mechanical performance, environmental responsiveness and biocompatibility – features rarely coexisting in traditional systems. Applications include 3D-printed bio-cement from engineered cyanobacteria that adapt calcite deposition to environmental cues, and nanoscale-structured synthetic coatings with antifouling properties. These advances mark a fundamental shift in how materials are conceptualized, designed and manufactured – reshaping sectors like healthcare, construction and environmental remediation.

Industry	Company	Outcomes
Agriculture, industrial biotech	Ginkgo Bioworks	Ginkgo Bioworks engineers microbes for biofabricated materials, bioplastics and biofuels, optimizing bioproduction processes and reducing environmental impact
Construction industry	Biomason	Bio-cement enables sustainable building materials, enhancing environmental impact reduction, material durability and operational efficiency.

Energy optimization materials

At the intersection of materials science and energy technology, energy optimization materials are transforming how energy is generated, stored and consumed. Materials such as perovskite photovoltaics address critical challenges in sustainability and efficiency by dynamically adapting to environmental conditions. While this technology has been in development for years, recent breakthroughs in simulation, modelling and automation have significantly accelerated its advancement and real-world application.





By combining advanced materials, AI and next-gen energy systems, this pattern is reshaping industries from construction to semiconductors. AI accelerates material optimization and system control, while materials like synthetic diamond enhance heat dissipation in electronics. AI-driven microgrids that integrate solar and energy storage exemplify this convergence, enabling smarter, more efficient energy solutions at scale.

Industry	Company	Outcomes
Climate industry	Made of Air	This technology converts biomass waste into carbon-negative materials, like biochar-based plastics, to combat climate change.
Chemistry industry	Materion	High-performance advanced materials enhance the durability of fuel cells, oil and gas exploration, solar panels and wind turbines.

Convergence transformation

The evolution and convergence of advanced materials represents a fundamental transformation in how material design, manufacturing and implementation are approached. The advancement of advanced materials technologies is becoming a critical enabler for progress in various sectors, enhancing the performance, durability and sustainability of next-gen technologies. The global advanced materials market is experiencing rapid growth, driven by cross-domain value creation and the ability to achieve enhanced functionality through the combination of diverse materials. This trend is particularly evident in industries such as aerospace, automotive, sustainable construction, healthcare and energy, where smart adaptive materials are unlocking new capabilities and expanding market opportunities.

The investment landscape is also evolving – from long-term, capital-expenditure-intensive commitments in traditional materials to increased access to financing through venture capital and strategic partnerships. Notable recent investments by Microsoft, Breakthrough Energy, CRH Ventures and various EU grant programmes underscore the growing significance of advanced materials convergence in enabling broader technological innovation.

A key objective of emerging advanced materials policies is to strengthen strategic sovereignty. By promoting innovation in advanced materials, policy-makers aim to reduce dependency on certain critical raw materials and provide viable alternatives that support long-term industrial resilience and sustainability.

CASE STUDY 9

Citrine informatics

Citrine is an AI platform for data driven materials and chemicals development. The platform integrates large-scale data from simulation outputs to experimental results and scientific literature, the platform applies AI to predict how materials and chemicals will perform under a wide range of conditions.

Combining AI and advanced materials has enabled clients to achieve their R&D, product development and manufacturing milestones more efficiently, reducing the time and cost of new materials development, as it is reducing the number of experiment iterations needed.

Bio-engineered materials for recycled plastic

Citrine accelerates the development of compounds using recycled content to meet customer and market demands, supply chain volatility, and emerging regulatory and sustainability initiatives.

AI modelling for energy storage

Citrine's AI models support electrolyte formulation and component design to accelerate development timelines, optimize resource use across the supply chain and ensure materials meet targeted performance criteria.

On the horizon

As the convergence of advanced materials technology progresses, compounding effects such as accelerated material discovery and cost-effective manufacturing are reshaping the innovation landscape. These effects are setting the stage for the next generation of material breakthroughs, unlocking novel applications across industries.

The evolution of material modelling and data-driven discovery is redefining how materials are designed and optimized. AI-powered computational tools, high-throughput simulations and ML-driven material prediction are significantly shortening development cycles. These advancements enable researchers to identify, test and refine new materials with unprecedented speed and accuracy, paving the way for more efficient and sustainable material solutions. The combination of AI-enhanced modelling with automated experimental validation will further accelerate the deployment of next-gen materials.

A transformative shift is also occurring with the rise of quantum-enhanced materials. Quantum-enhanced materials harness quantum phenomena such as superposition and entanglement to deliver exceptional electrical, magnetic and thermal properties. Materials like topological insulators, graphene, quantum dots and high-temperature superconductors are pushing boundaries in sensing, energy and computing – engineered through quantum modelling or designed to interface with quantum systems for next-gen performance.

The strength of these convergence patterns lies in their ability to reinforce each other – data-driven material discovery accelerates experimental validation, quantum computing enhances precision and smart materials broaden application possibilities. Together, they create a reinforcing cycle that is poised to transform how materials are designed, produced and integrated across industries.

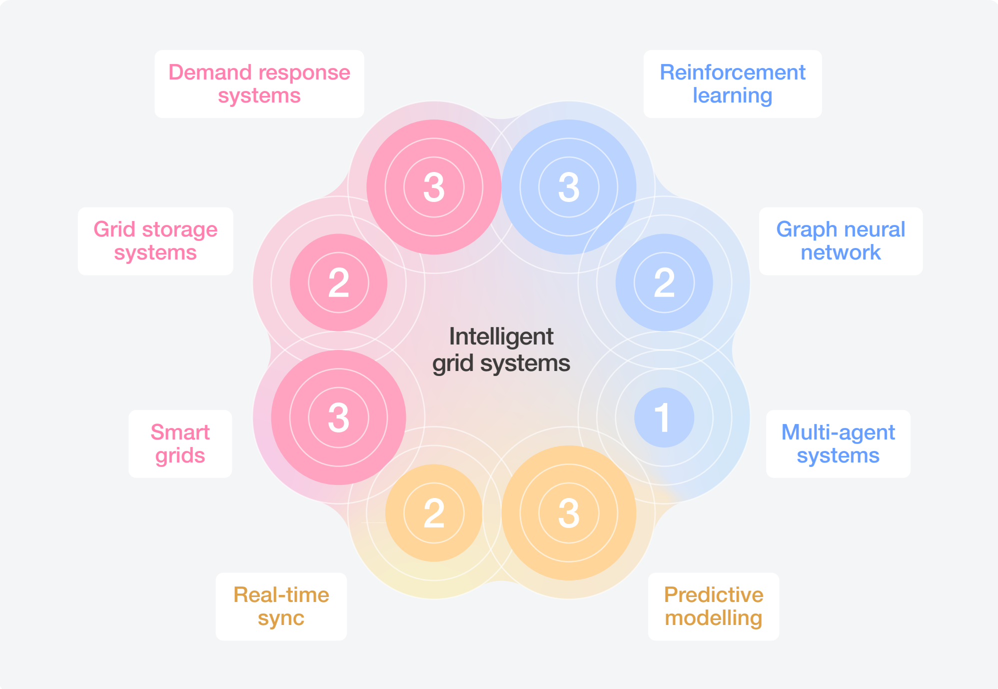
2.7 Next-gen energy domain

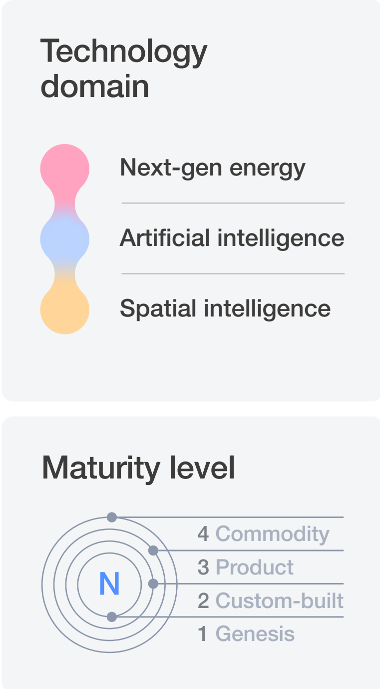
Next-gen energy represents a fundamental shift in how energy is generated, distributed and used. In a business world shaped by the energy transition, these technologies offer a pathway towards accelerating tech innovation and scalability. Their success depends on interoperability and integration across platforms and protocols, which are key to ensuring traceability and transparency across global value chains and building a more sustainable, efficient and resilient energy ecosystem at scale.

Innovative approaches like peer-to-peer energy trading and dynamic load-balancing systems are driving more decentralized and adaptive energy distribution, while advanced thermal energy storage is enhancing efficiency and sustainability. Meanwhile, established technologies such as smart grids, renewable energy generation and industrial energy management ensure the stability and scalability required for widespread adoption. Smart grids enable real-time monitoring and optimization of energy flows, renewable energy generation is expanding clean power sources, and industrial energy management enhances efficiency across sectors.

Intelligent grid systems

This combination represents a shift in how electrical power is distributed and managed. Integrating AI-driven predictive analytics with IoT-enabled sensor networks is transforming static, centralized power grids into adaptive, self-balancing networks. Power utilities can now monitor energy flows in real-time, forecast renewable energy output with accuracy, and dynamically adjust to fluctuations in both supply and demand. The immediate impact is significant: AI systems mitigate challenges like the "duck curve" by intelligently aligning demand with supply fluctuations, while automated demand response mechanisms use real-time pricing signals to shift energy consumption to optimal windows, reducing peak load stress and operational costs.



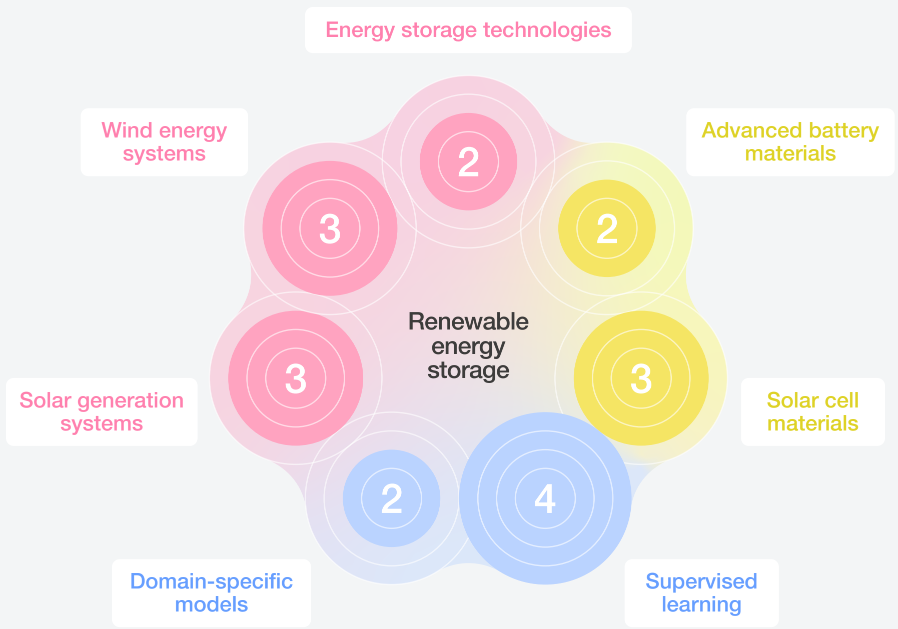


What makes this convergence particularly powerful is its foundation on standardized protocols and architectures that ensure interoperability across the grid ecosystem. With edge computing nodes processing localized demand signals at substations, utilities achieve dramatically reduced latency compared to legacy systems, while federated learning frameworks enable collaborative model training without compromising data privacy. This is being implemented today by US utilities, delivering a clear ROI via reduced outages, lower maintenance costs and optimized renewable integration. The combination effectively transforms the traditional one-directional distribution system into a flexible, responsive network that turns the volatility inherent in renewable energy sources into grid resilience and reliability. The technical maturity of these systems ensures a low barrier to widespread implementation.

Industry	Company	Outcomes
Automotive	Camus Energy	A smart grid for EV fleets optimizes charging patterns during periods of grid constraints, lower costs and ensure fleet operations remain uninterrupted.
Agriculture	Edgecom Energy	Edgecom Energy provides an energy management platform that helps the agriculture industry manage and reduce peaks in energy consumption.

Renewable energy storage

The convergence of renewable energy generation with advanced storage technologies and intelligent control systems is creating a powerful solution to the long-standing challenges of renewable intermittency and grid stability. This integration pattern combines next-gen battery technologies with AI-driven predictive capabilities to transform passive energy storage into active, responsive grid assets. While lithium-ion batteries continue to dominate due to their proven efficiency and lifespan, emerging technologies like solid-state batteries with higher energy density and scalable vanadium flow batteries are enabling the critical long-duration storage needed for wind and solar integration. These systems effectively time-shift excess renewable generation to peak demand periods, dramatically reducing curtailment and maximizing clean energy use across the grid.



Technology domain

- Next-gen energy
- Advanced materials
- Artificial intelligence

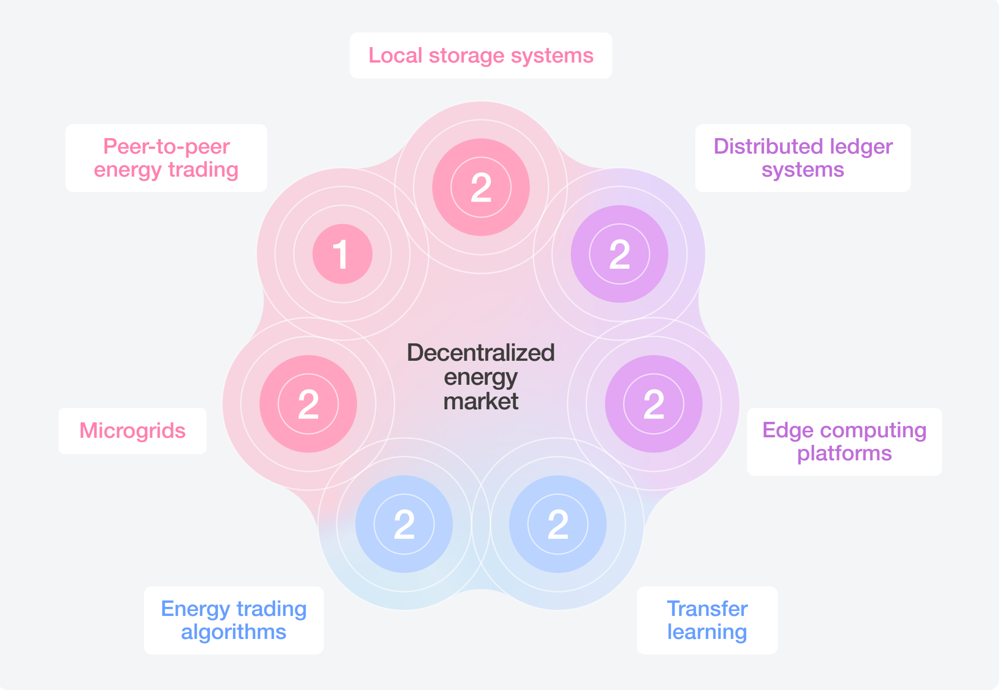
Maturity level

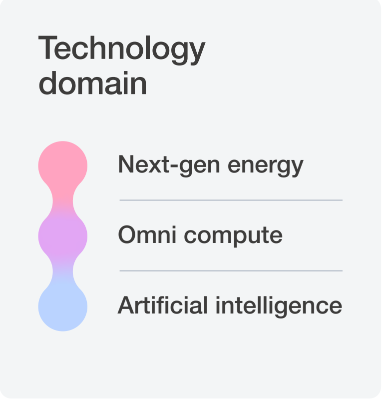
What makes this combination particularly transformative is the role of AI as the orchestrating force. AI algorithms optimize battery performance through predictive maintenance, extend battery life cycles through intelligent charge management and forecast energy demand patterns to align storage discharge with real-time grid needs. When these capabilities are integrated with IoT-enabled grid management and smart building systems, they create comprehensive energy ecosystems capable of achieving unprecedented renewable penetration rates. The impact extends beyond utilities to multiple sectors, from manufacturing facilities using price arbitrage to reduce energy costs to data centres deploying specialized storage solutions for high-demand AI workloads. This convergence shifts storage from a passive buffer to an intelligent, proactive component that enables truly resilient and renewable-powered infrastructure.

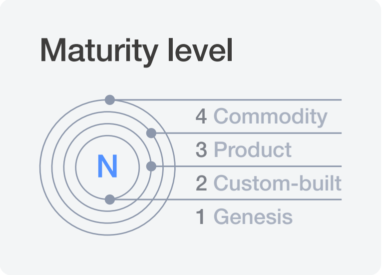
Industry	Company	Outcomes
Consumer goods	Enpal	An integrated renewable energy solution optimizes energy production and consumption, reduces reliance on the grid, and lowers energy costs.
Utilities	AlphaESS	Energy storage maximizes energy independence and reduces reliance on the grid across residential, commercial and industrial applications.

Decentralized energy market

The combination of decentralized energy networks is reshaping traditional approaches to power distribution and energy markets. Its impact lies in shifting away from the conventional model of centralized power plants supplying passive consumers towards a more flexible system where energy flows in multiple directions, and participants can function as both producers and consumers. At its core, this pattern integrates blockchain-enabled peer-to-peer trading, federated learning for grid optimization and interoperable storage systems to create resilient local energy communities. Real-world implementations are already showing impressive results: pilot projects in Germany and Portugal have shown significant cost reductions for participants,[26] while Amsterdam's residential microgrids use federated learning to improve demand forecasting accuracy while preserving privacy. The INTERSTORE project demonstrates the benefits of interoperability standards in unifying diverse storage assets and improving efficiency.[27]







The adoption of decentralized energy networks is increasing. While core technologies – such as custom-built microgrids, local storage and digital grid controls – are in place, their full integration requires further development. Decentralized energy systems will depend on the maturation of blockchain-based energy trading, interoperable storage systems and advanced control software. Still, steady progress in storage technologies and grid intelligence is laying the groundwork for this next wave.

Industry	Company	Outcomes
Energy	Grid Singularity	Grid Singularity enables energy trading and increases market transparency, empowering local energy markets for more flexible and cost-effective energy systems.
Energy	Powerledger	Powerledger enables transparent, secure and efficient peer-to-peer energy trading for renewable energy production.

Convergence transformation

In a world where energy efficiency and sustainability are increasingly important, next-gen energy convergence plays a crucial role in advancing the energy transition across industries. These combinations enable organizations to extend their value chain footprint, anticipating future energy challenges of our world and strengthening their competitive advantage. AI, for example, plays a pivotal role in this transition by managing energy with intelligence. The widespread adoption of intelligent grid systems by companies demonstrates their importance as a prerequisite for integrating large-scale renewable energy systems. These smart grids not only enhance the efficiency of energy distribution but also mitigate the risks associated with energy supply chains.

There is a shift from investment in capital-intensive, large energy infrastructure to more integrated smart energy platforms that combine AI with technologies such as omni compute, robotics, engineering biology and spatial intelligence. As energy technology components grow increasingly complex, investment in custom-built maturity sentiment levels technologies could significantly accelerate the emergence of new combination patterns. These investments are expected to drive significant progress in energy solutions. Private markets are playing a pivotal role in scaling these next-gen energy solutions. By combining capital, commercial expertise and operational knowledge with corporate and institutional investments, they are unlocking new value creation models and expanding the broader energy ecosystem.

Ultimately, the convergence of advanced energy technologies is transforming value chains far beyond the utility sector. The integration of physical infrastructure with digital intelligence is reshaping how energy is generated, distributed and consumed, paving the way for resilient, adaptive and sustainable energy systems of the future.

CASE STUDY 10

Saudi Aramco

By incorporating AI, blockchain and digital twins, Saudi Aramco is developing advanced solutions tailored to facility monitoring, predictive maintenance, autonomous drone operations and intelligent grid systems, contributing to greater operational efficiency, reliability and sustainability.

The benefits of these technological advancements minimize its carbon footprint while enhancing operational efficiency.

Intelligent grid for real time optimization

Aramco's intelligent grid uses AI, blockchain and edge computing for real-time energy optimization and fault detection. In partnership with Microsoft and Armada, it launched containerized edge data centres to scale AI-driven energy efficiency and digital transformation.

Digital transformation for downstream operations

Following its acquisition of SABIC, Aramco integrated digital twins, blockchain to map Scope 3 emissions and edge control across plants. This fusion improved process optimization, reduced emissions and enhanced agility in industrial operations across global chemicals and materials markets.

On the horizon

As next-gen energy convergence takes hold, compounding effects such as increased adoption and cost reduction are emerging. These compounding effects are setting the stage for the next wave of technological combinations, further accelerating the energy transition.

New forms of energy generation will begin to emerge, led by advancements in fusion power. Multiple companies are advancing distinct technological pathways. One approach is magnetic confinement fusion with Commonwealth Fusion Systems' tokamak-based approach, and Proxima Fusion and Thea Energy are employing stellarators. The other pathway to fusion is laser-driven fusion with organizations such as Marvel Fusion. Breakthroughs in materials science, AI-supported plasma control and computational design are expected to support the complex design process and manufacturing required for these approaches. At scale, fusion could dramatically reduce energy costs while providing abundant zero-emission energy. Beyond power generation, fusion is also expected to impact other sectors such as hard to decarbonize industrial heat, aerospace and logistics – particularly marine propulsion.[28] Another promising path is the deployment of small modular nuclear reactors (SMRs). Paired with AI simulations, advanced materials, and robotics for safety and maintenance, SMRs could provide reliable, flexible and cleaner energy solutions while entering new industrial value chains.

In parallel, as intelligent grid systems and the decentralized energy market matures, the development of autonomous energy ecosystems will represent the most ambitious but achievable scenario. The combination of intelligent grid systems with decentralized energy markets is creating self-organizing networks that optimize efficiency, cost and environmental impact. Achieving this requires significant advancements in key technologies, but current product-stage grid management systems and custom-built optimization platforms provide a clear development pathway.

The strength of these convergence patterns lies in their interdependence – intelligent grids enhance renewables, decentralized systems improve resilience and efficiency measures ease system demands. Together, they create reinforcing cycles that could accelerate energy transformation.

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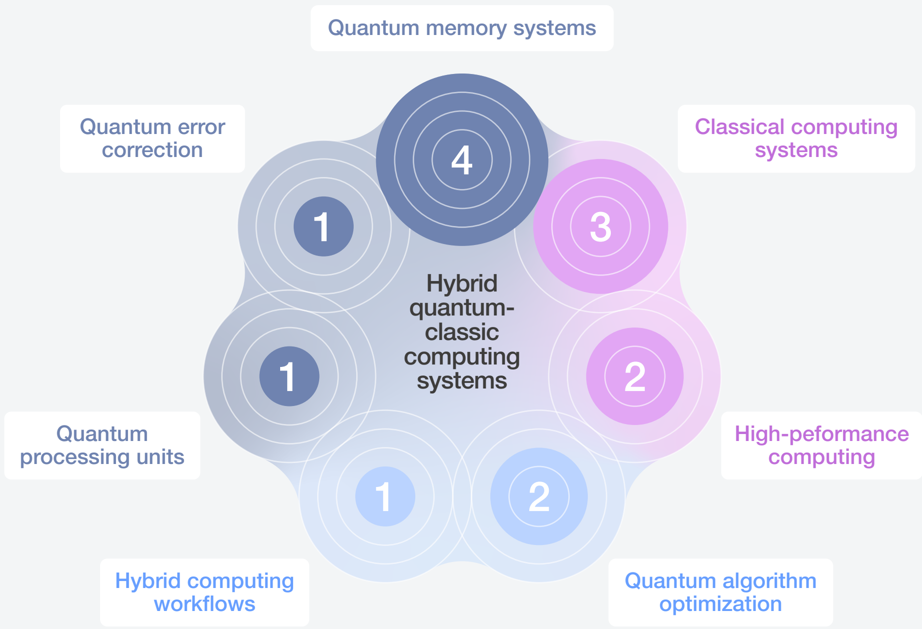
2.8 Quantum technologies domain

Quantum technologies represent perhaps the most transformative yet challenging technological frontier, pioneering a new era of computational, communication and sensing capabilities. Quantum computing has the capacity to address some of the most complex and previously unsolvable challenges. Quantum communication technologies offer enhanced security capabilities, while quantum sensors enable unprecedented levels of measurement precision, both on Earth and in space.

Emerging quantum capabilities, including quantum entanglement distribution, quantum memory materials and quantum repeaters, are driving advancements in ultra-secure communication, scalable quantum networking and quantum information processing. These innovations are supported by foundational technologies like atomic clocks, quantum key distribution and quantum sensors, which provide stability for real-world applications. Together, they pave the way for enhanced precision measurement, secure data transfer and quantum-classical hybrid computing.

Hybrid quantum-classical computing systems

The combination of hybrid quantum-classical computing systems offers a practical and immediate way to tap into quantum capabilities. Its relevance lies in the ability to integrate the emerging potential of quantum computing with the established reliability of classical systems. This approach serves as a bridge between the deterministic nature of classical computing and the probabilistic, parallel characteristics of quantum mechanics, allowing for more feasible near-term applications.



Technology domain

- Quantum
- Omni compute
- Artificial intelligence

Maturity level

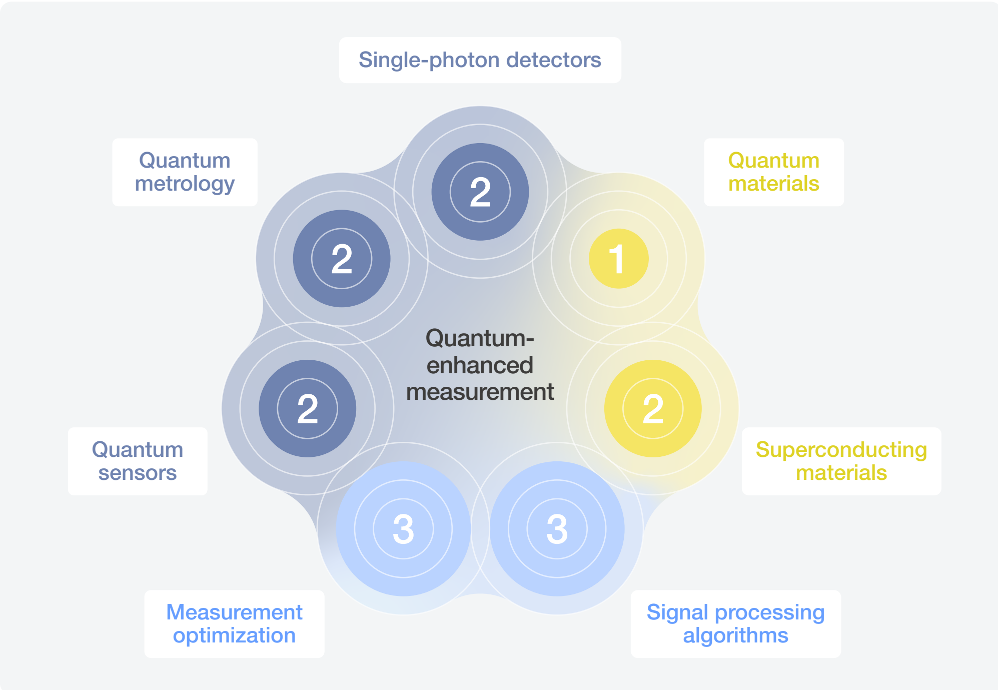
Hybrid quantum-classical computing, combining quantum and AI, is driving breakthroughs in finance, materials or molecular simulation, drug discovery, and complex optimization problems. Quantum processors accelerate AI model training, while classical systems ensure stability and scalability.

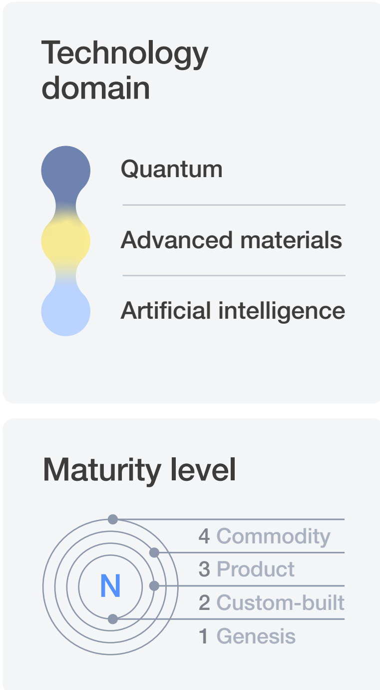
Industry	Company	Outcomes
High-tech	Planqc	Neutral-atom quantum computers enhance computational efficiency, accelerate complex problem-solving and expand quantum accessibility via cloud and supercomputing workflows.
Chemicals and materials	Bosch and IBM[29]	Bosch and IBM are developing a hybrid quantum-classical workflow to model strongly correlated materials with greater precision, with potential applications in renewable energy, electromobility and magnetic resonance imaging (MRI) technologies.

Quantum enhanced measurement

The combination of quantum-enhanced precision instruments integrates quantum principles with measurement technology, improving our ability to measure physical properties with unprecedented accuracy. This approach is crucial in quantum positioning, navigation and timing (QPNT), as well as in medical research. Modern atomic clocks, using quantum effects, lose less than a second over the entire age of the universe.

These clocks support GPS accuracy and can even provide an alternative to GPS through quantum magnetometers – devices that detect changes in magnetic fields with extreme precision – to create a unique fingerprint of the earth's magnetic field for precise geopositioning. Such accuracy also underpins financial trading and telecommunications synchronization. In medicine, quantum-enhanced magnetic sensors detect weak neural signals with superior sensitivity, improving brain activity studies. By expanding measurement capabilities rather than just refining them, quantum technology is redefining precision across multiple fields.



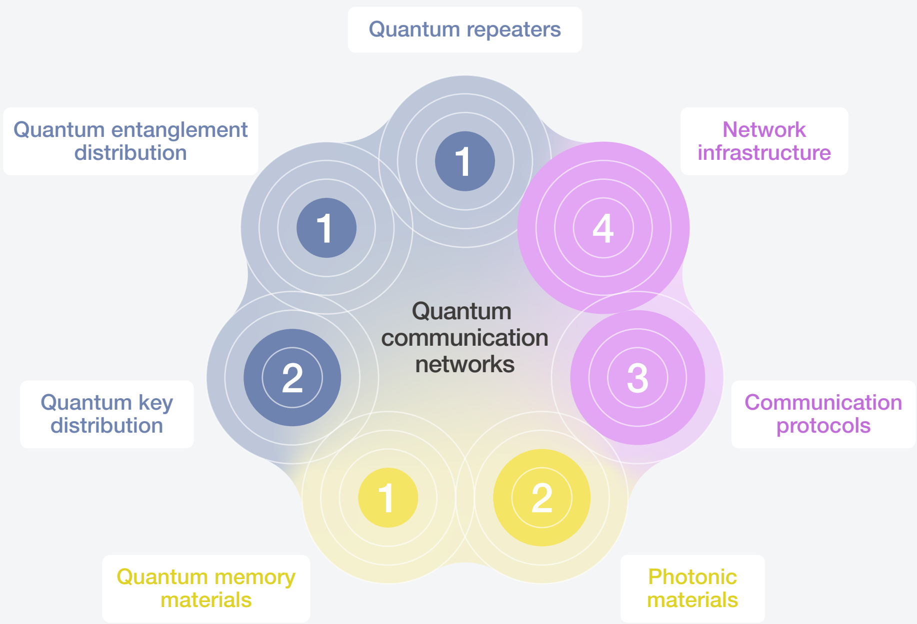


Quantum-enhanced measurement, integrating quantum sensing, advanced materials and AI are transforming aerospace and geophysics with ultra-precise sensing. Medical diagnostics benefit from enhanced imaging, while aerospace uses quantum sensors for navigation in GPS-denied environments. Geophysical exploration improves through high-sensitivity measurements.

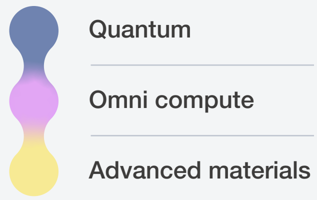
Industry	Company	Outcomes
Aerospace and maritime industries	Q-CTRL	QPNT enhances maritime navigation with more precise real-time positioning.
Aerospace and defence	AOSense	Quantum-sensing solutions enable precise measurements of rotation, acceleration, time and frequency, and gravity and gravity gradients

Quantum communication networks

The combination of quantum communication networks represents an ambitious development in the quantum field. Its significance lies in the potential to establish communication channels that are inherently secure, relying on physical principles rather than computational complexity. This is not merely an enhancement of existing security methods but a fundamental shift in how secure information transfer is approached.



Technology domain



Maturity level

Quantum communication networks, combining quantum, omni compute and advanced materials, are gaining traction across finance, telecommunications and defence for ultra-secure data transmission. Financial services are integrating quantum-secured transactions, while telecommunications providers explore quantum key distribution (QKD). Governments invest in quantum-resistant networks for cybersecurity.

Industry	Company	Outcomes
Banking and finance	JPMorgan Chase[30]	QKD secures multiple independent, high-speed virtual private networks (VPNs).
Telecommunications	ID Quantique	QKD systems and quantum random number generators enhance secure networks.

Convergence transformation

Companies are preparing for quantum technological breakthroughs to accelerate quantum adoption and disrupt industries such as energy, healthcare, finance, manufacturing, material science, transport and others.

This transition from high R&D costs primarily supported by public funding to a medium- to long-term strategy driven by private and venture capital investments highlights the need for a value-led approach. The current maturity level of these technologies indicates that significant investments are still required to accelerate their impact on industries and economies. This is evident from the substantial fundraising rounds secured by companies like Quantinuum and Rigetti Computing, as well as the considerable investments made by major corporations such as Microsoft, Google, Amazon and NVIDIA.[31]

CASE STUDY 11

SandboxAQ

Traditional AI relies on vast amounts of training data, making it inefficient for applications where complexity, uncertainty or atomic-level precision is required. SandboxAQ is closing this gap by integrating quantum science with AI to create large quantitative models (LQMs).

At its core, SandboxAQ's ecosystem is a continuous learning loop: quantum-driven simulations or inputs from quantum sensors create better data, which enhances AI models, which then improve real-world applications, generating even more refined data. Whether in biopharma (faster drug discovery), materials science (next-gen energy storage) or aerospace (GPS-free magnetic navigation), each breakthrough strengthens another, pushing the boundaries of computational accuracy.

By structuring its tech stack around cross-industry convergence, SandboxAQ is not just applying quantum and AI to solve today's problems, it is designing an ecosystem where compounding effects drive exponential advancements, setting the foundation for the next era of precision-driven intelligence.

Quantum enhanced next-gen energy storage

Using LQMs, NOVONIX and SandboxAQ reduced the time needed to predict lithium-ion battery end-of-life by 95%, with an unprecedented 35 times greater accuracy and 50 times less data than traditional approaches, reducing the time for cell testing from months or years to just days.

Quantum measurement for navigation

AQNav combines LQMs with quantum sensing capabilities tuned to the Earth's crustal magnetic field to enable passive, dual-use magnetic navigation in GPS-denied environments. The US Air Force is using AQNav to rapidly enable critical operations ensuring a strategic advantage and enabling mission continuity and safety.

Quantum simulation for drug discovery

One biotech institution increased the chemical exploration space from 250,000 molecules to 5.6 million by using SandboxAQ's platform. They identified candidate molecules faster and more efficiently with a 30-times-greater hit rate.

On the horizon

Quantum technology components remain largely in the genesis and custom-built maturity stages, but their transformative potential is already taking shape. As quantum advancements continue, their early impact is becoming evident across various industries.

The adoption of quantum sensing systems is advancing, with breakthroughs in photonics, materials science and control systems driving their development. Unlike quantum computing, quantum sensing does not require perfect coherence, making it more viable for near-term applications. For example, quantum-enhanced MRI could drastically improve imaging resolution while integrating with existing hospital equipment. Additionally, photonics-driven quantum sensors enable more precise control and transmission of quantum information, enhancing accuracy, miniaturization and compatibility with optical networks. These advancements are unlocking new possibilities across healthcare, navigation and environmental monitoring.

Beyond sensing, quantum technology convergence represents an early but significant effort to translate fundamental physics into practical applications. The impact extends beyond enhancing existing methods – quantum technologies are poised to enable entirely new capabilities. In fields such as secure communications, drug discovery and optimization, quantum technologies could introduce breakthroughs that redefine industry standards. While many challenges remain, particularly in scaling quantum systems and overcoming decoherence, ongoing advancements in hardware and software integration are laying the foundation for a new era of quantum-enabled solutions.

Conclusion

As industries transform through technological convergence, the way organizations position themselves in this landscape will have a lasting impact on their growth trajectories. Strategic leaders are already assessing their value chain positions and identifying adjacent opportunities where technology combinations create competitive advantages.

The most forward-thinking organizations are already developing cross-domain expertise that bridges traditional silos, creating strategic portfolios that blend mature and emerging technologies, building ecosystems and partnerships that accelerate convergence capabilities and establishing governance frameworks that address emerging ethical concerns.

While encouraging innovation is essential, organizations must also be mindful of the potential for dual-use technologies to be misused or have expanded unintended consequences. In reference, the World Economic Forum has ongoing bodies of work to address these various areas. The AI Governance Alliance[32] looks at challenges related to advancing responsible and impactful AI adoption. The Defining and Building the Metaverse[33] initiative reported on governance for building interoperable, safe and inclusive spatial environments. Initiatives such as DRIVE-A[34] and AVIATE[35] examine questions of safety, ethics and accountability for autonomous vehicles and aviation. Meanwhile, the Bioeconomy Initiative[36] and Quantum Initiative[37] look broadly at opportunities and concerns of transitioning to bio- and quantum-based economies respectively.

Balancing potential and risks and adapting quickly will be key to success, as the convergence paradigm waits for no one. Companies that hesitate risk being left behind as nimble competitors reshape value chains and redefine industry boundaries. Those who move strategically now will capture disproportionate value as these technologies compound.

The initiative led by the World Economic Forum and Capgemini will continue to examine the dynamics of convergence and the frameworks needed to harness its possibilities. Ultimately, the question is no longer whether technological convergence will reshape industries, but how that transformation will happen, and who can become champions of convergence.

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