# The Hard Tech Report









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## A Letter from Our Founder

In an era defined by unprecedented global challenges, the question is no longer whether hard tech will transform our world, but who will lead this transformation. For over 25 years, Pangaea Ventures has stood at the intersection of scientific breakthrough and commercial opportunity.

We've witnessed firsthand how materials science, advanced The manufacturing, and biological innovation can solve problems resultat software alone cannot address. From climate resilience resource scarcity, from healthcare transformation to resultation industrial reinvention, the most pressing issues of our time the demand tangible, physical solutions.

This report arrives at a pivotal moment. While broader markets recalibrate, hard tech is experiencing a renaissance. We're seeing the convergence of multiple forces persist even in the face of recent global tariffs: Al-accelerated discovery, the collapse of development timelines, proliferation of chronic diseases, urgent environmental imperatives, and shifting geopolitical priorities that are driving nations to secure technological sovereignty. The result is a perfect storm of innovation that is creating extraordinary opportunities for those who understand how atoms, not just bits, will reshape our world.

What sets Pangaea apart is our unwavering focus on capital-efficient hard tech. We've proven that breakthrough physical innovation doesn't require decades or billions to commercialize. Our portfolio companies—from Redlen Technologies' revolutionary medical imaging systems to Prime Roots' mycelium-based proteins—demonstrate how scientific ingenuity can rapidly translate into marketready solutions that generate both exceptional returns and meaningful impact.

The companies we support aren't developing incremental improvements; they're pioneering entirely new categories. They're transforming  $CO_2$  into valuable materials, reinventing semiconductor manufacturing, revolutionizing regenerative medicine, and building the infrastructure for a resource-efficient future. These aren't distant moonshots, they're scalable innovations already beginning to reshape industries.

I founded Pangaea twenty-five years ago with the conviction that the most profound advances would emerge from the physical sciences. Today, that vision is being validated as we witness the inevitable rise of hard tech. The next wave of trillion-dollar companies won't be built solely in code; they'll be forged in laboratories, pioneered in advanced manufacturing facilities, and scaled through the precise manipulation of advanced materials, chemistry and biological systems.

This report offers a window into that future; a roadmap to the technologies that will define not just markets, but the very foundation of how we produce, consume, and thrive on this planet. At Pangaea, we're not just investing in companies; we're catalyzing an industrial transformation that will generate exceptional returns while building a more resilient, sustainable world. The hard tech revolution isn't coming, it's here. And we're proud to be leading it.

**Chris Erickson** Founder, Pangaea Ventures







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## Drivers of the New Investment Imperative

In a world facing unparalleled global challenges, traditional business models are under intense pressure to evolve. Scarcity of critical metals, mounting water security concerns, and escalating environmental pressures are not only reshaping industries, they are creating an urgent need for transformative, hard tech solutions. Rapidly shifting socio-political priorities and a rising public demand for accountability are forcing governments and companies to rethink long-standing practices. This convergence of challenges is sparking a wave of technological innovation that can both address these pressing issues and unlock long-term value. In particular, hard tech —including advanced materials, quantum computing, fusion energy, and synthetic biology—is emerging as the linchpin for this new investment

#### **GLOBAL IMPERATIVES**

The scale of today's challenges requires bold, disruptive responses. Global temperatures in 2024 were about 1.55°C above pre-industrial levels<sup>1</sup> and are on track to continue rising<sup>2</sup>. Annual clean energy and energy transition investment must surge to over \$4 trillion by 2030 to limit global warming<sup>3</sup>. Meanwhile, 40% of the world's population faces clean water scarcity, and 1.8 billion may face absolute water scarcity this year<sup>4</sup>. Incremental improvements are simply not enough. These stark realities have triggered a global race for technological primacy, where national security interests, commercial ambitions, and regulatory advantages converge. First movers in hard tech will not only capture market share—they will shape entire ecosystems, establish regulatory frameworks, and set industry standards that competitors will be forced to follow. In this race, the winners will control supply chains and intellectual property, creating decades-long competitive moats that have the power to reshape both geopolitical influence and industrial leadership for generations.

- 2. https://climateactiontracker.org/global/emissions-pathways/
- 3. https://www.weforum.org/stories/2023/09/iea-clean-energy-investment-global-warming/



Annual clean energy and energy transition investment must surge to over

## \$4 trillion by 2030

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of the world's population faces clean water scarcity

## 1.8 billion

people may face absolute water scarcity this year







<sup>1.</sup> https://wmo.int/news/media-centre/wmo-confirms-2024-warmest-year-record-about-155degc-above-pre-industrial-level

<sup>4.</sup> https://www.international.gc.ca/world-monde/issues\_development-enjeux\_developpement/environmental\_protection\_protection\_environnement/water-eau.aspx?lang=eng



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#### **ECONOMIC DRIVERS**

At its core, the move toward hard tech is driven by the economics of scarcity and efficiency. For example, raw material costs have surged and global supply chains have grown increasingly volatile: Raw lithium prices surged to record highs in 2022 before plunging over 80% from their peaks. These pressures demand more resilient production processes which are compelling industries to invest in technologies that optimize resource use, allow for domestic manufacturing and enable circular economies. Companies in sectors such as advanced materials, semiconductors and automation have already shared improvements in efficiency, translating into lower production costs and reduced exposure to market shocks. Investors who recognize these economic drivers will be well positioned to benefit from businesses that convert these challenges into competitive advantages.



#### SOCIO-POLITICAL FACTORS

These economic pressures do not exist in isolation. Across the globe, geopolitical shifts and policy recalibrations are transforming how nations approach everything from global trade to environmental accountability. In many regions, re-shoring manufacturing and boosting regional self-reliance have become key priorities, driven by rising trade barriers and concerns over supply chain vulnerabilities.

Global tariffs recently announced by the US, with some being implemented and others deferred, are causing significant market confusion, with long term impacts yet to be fully understood.

Recent policy shifts under the Trump administration have deprioritized climate action, instead emphasizing expanded oil and gas development and rolling back federal support for clean energy initiatives, intensifying debates about the role of regulation in addressing climate change and safeguarding natural resources while preserving economic competitiveness. In contrast, the European Union and parts of Asia continue to push for stricter environmental standards. As governments seek to secure both energy and economic sovereignty, investments in hard tech are emerging as a dual engine, driving industrial growth while setting new industry standards. Companies that lead in innovations like semiconductors, advanced materials, and quantum computing are not just capturing market share; they are also influencing policy frameworks and building public trust, creating long-term competitive moats in an increasingly protectionist global landscape.





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## A Defining Era

As we navigate unprecedented technological advancements and global challenges, investment in hard tech has never been more crucial. With traditional production models under strain from resource scarcity, environmental degradation, and water stress, hard tech innovation isn't just an environmental necessity—it's an economic imperative. From Al-led semiconductor breakthroughs to biofabrication transforming supply chains, hard tech is poised to be the foundation of the next industrial revolution.

### At Pangaea Ventures, we define hard tech as physical, deeply technical, and highly impactful innovations that transform industries and solve global challenges.

While some hard tech ventures are indeed capital intensive—demanding substantial infrastructure and long development cycles—many breakthroughs in fields such as materials, chemistry, and biology follow a more capital-light model. Regardless of the capital model, these innovations share a common ability to disrupt traditional industries and lay the foundation for the next industrial revolution.

Hard tech represents a unique investment category where breakthrough science meets scalable, high-margin commercialization opportunities. The sector is characterized by higher capital intensity but offers correspondingly higher potential returns through defensible intellectual property and significant barriers to entry.

#### WHAT IS HARD TECH?

Hard tech encompasses innovations rooted in tangible, physical technologies. Unlike software, which primarily operates in virtual or digital domains, hard tech drives advancements in advanced materials, chemistry, biology, and processes. Examples include semiconductors, medical imaging devices, green chemistry, and grid-scale battery solutions. These innovations require a deep interplay of engineering, advanced materials, and manufacturing processes, often demanding significant time, expertise, and resources to develop and scale.



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# Why Hard Tech? Why Now?

Hard tech represents the tangible, engineering-driven solutions needed to address the fundamental shifts in how we produce, consume, and manage resources.







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## Why Hard Tech? Why Now?

There is an inevitability about the innovation occurring currently in hard tech. The breakthrough innovations in sectors like advanced manufacturing, semiconductor design, and sustainable energy aren't just incremental improvements; they're transformative shifts driven by the physical realities of resource scarcity and the need for resilient systems.

In a world where traditional processes are increasingly unsustainable, investing in hard tech is no longer optional—it's imperative. These technologies not only offer the promise of efficiency and cost savings but also provide strategic advantages in terms of supply chain resilience, economic sovereignty, and competitive differentiation.

## In short, hard tech is positioned at the nexus of innovation and necessity.

#### SHIFTING PARADIGMS

Today's investment environment is being reshaped by government responses to dramatic geopolitical and resource challenges. Enhanced support through subsidies and public private partnerships is narrowing the gap between the traditionally rapid returns of software and the longer-horizon potential of hard tech. This trend is evidenced by breakthroughs in renewable energy and innovations underpinning advanced manufacturing processes. For example, recent advancements in green chemistry and biology are enabling the development of everyday commodity materials from carbon dioxide or methane instead of petrochemical feedstocks, while progress in battery technology is driving grid-scale energy storage solutions that better integrate intermittent renewable sources. As these technologies mature, we can expect key ROI metrics—such as higher internal rates of return and shorter payback periods—to improve, thanks to decreased risk premiums and a more predictable investment environment.





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#### **EVOLVING TRADITIONAL ROI PERSPECTIVES**

Historically, hard tech investments have been characterized by longer development cycles and a higher capital intensity compared to software. However, this narrative is shifting as key characteristics such as accelerated value realization, transformation potential and increased predictability have begun to return critical benefits in the hard tech investment conversation, and seed an ROI conversation beyond, but not ignoring, the financial:

#### **Key Features of Hard Tech Investing**



#### Accelerated Value Realization

With historically robust government backing and strategic market incentives, the time to profitability for hard tech is shortening. A more secure domestic market and targeted infrastructure investments are leading to earlier revenue recognition. A recent global study by McKinsey found that top performing companies are investing heavily in innovation to hedge against disruption in this highly uncertain business environment.<sup>5</sup>



#### Value and Industrial Transformation Potential

As the convergence between hardware and software deepens—with digital tools optimizing production and reducing marginal costs—hard tech ventures are beginning to see competitive internal rates of return (IRR) and multiples on invested capital (MOIC). The strategic premium associated with technologies that address critical societal needs is also driving up overall valuations.



#### Increased Predictability

Policy stability and targeted support lower uncertainty, enhancing net present value (NPV) by creating more reliable long-term cash flows. This new environment not only improves the financial outlook for hard tech but also aligns investment returns with the broader social and environmental impact.

#### **EMBRACING CONVERGENCE AND INNOVATION**

One of the most exciting trends in the hard tech sector is its dynamic convergence with digital innovation. The integration of artificial intelligence, IoT, and data analytics with hardware solutions is revolutionizing product performance and operational efficiency. This hybrid approach is bridging the gap between the agility of software and the tangible impact of physical technologies, unlocking scalable business models that deliver robust, long-term returns.

As these innovations continue to blur traditional industry lines, investors are beginning to recognize that hard tech is no longer a distant, high-risk frontier. Instead, it is evolving into a dynamic, impactful domain where cutting-edge research meets real-world application a domain where early investments can yield not only substantial financial rewards but also drive significant social and environmental benefits.





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## Understanding the Hard Tech Landscape

At Pangaea Ventures, we organize the vast landscape of hard tech into three primary focus areas:



#### CLIMATE INNOVATION & SUSTAINABLE SYSTEMS

These are hard tech innovations designed to directly address climate resilience, resource sustainability, and environmental health. They include technologies that improve energy efficiency, reduce greenhouse gas emissions, optimize resource use, and safeguard ecosystems. Investments in this area are pivotal in creating sustainable industrial processes that reduce environmental impact and secure long-term economic stability.



#### COMPUTATIONAL & PHYSICAL INFRASTRUCTURE

This category underpins the modern economy with foundational technology platforms. It encompasses advancements in semiconductors, artificial intelligence–driven discovery, and biological manufacturing, all of which drive efficiency and innovation across multiple sectors. These breakthroughs enable the rapid processing of data, the development of novel materials, and the creation of more resilient and efficient physical networks—cornerstones of the new industrial era.



#### HUMAN HEALTH & BIOENGINEERING

Investments in this area focus on breakthroughs that improve human health and redefine biological production. This includes innovations in medical imaging, biomanufacturing, regenerative medicine, and genomics. These technologies not only have the potential to transform healthcare and improve quality of life, but they also represent a significant market opportunity as healthcare systems evolve and demand more personalized treatments.

In the chapters ahead, we will dive deeper into these three distinct, yet interconnected domains. Each section provides an overview of the breakthrough science and strategic investment opportunities developing in hard tech.





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#### THE HARD TECH INVESTMENT LANDSCAPE



## Climate Innovation & Sustainable Systems

AGRICULTURE & FOOD SYSTEMS

GREEN CHEMISTRY & INDUSTRIAL BIOLOGY

**ENERGY & GRID SOLUTIONS** 

CIRCULAR ECONOMY & RESOURCE RECOVERY



## Computational & Physical Infrastructure

SEMICONDUCTORS

ADVANCED MANUFACTURING & MATERIALS

COMPUTATIONAL DISCOVERY PLATFORMS

BIOLOGICAL INFRASTRUCTURE & MANUFACTURING Human Health & Bioengineering

**PREVENTATIVE CARE & DIAGNOSTICS** 

REGENERATIVE MEDICINE & BIOPRINTING

GENOMICS & PERSONALIZED MEDICINE



## Cross Cutting Themes



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While our report organizes hard tech innovations into the three primary focus areas just outlined, it's important to note that several key enablers cut across these categories, driving systemic change and creating interdependent value chains. These cross cutting themes not only accelerate breakthroughs within each sector but also catalyze the broader transformation of the global innovation ecosystem.

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#### AI & AUTOMATION: ACCELERATING DISCOVERY, PROCESS OPTIMIZATION, AND AUTONOMOUS SYSTEMS

Al and automation have emerged as critical multipliers for innovation. By harnessing advanced algorithms and machine learning, these technologies accelerate the discovery of new materials and drugs, dramatically reducing time-to-market. They also streamline complex manufacturing processes enhancing quality control, reducing operational costs, and enabling self-optimizing supply chains. Autonomous systems, powered by Al, are redefining operational efficiency across sectors, from intelligent robotics in manufacturing to dynamic process management in energy systems.

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### **DECENTRALIZATION & MODULAR SYSTEMS:** ENABLING ON-DEMAND, DISTRIBUTED PRODUCTION

Traditional centralized production models are evolving towards more flexible, decentralized systems that can rapidly adapt to local and global market needs. Modular production units facilitate on-demand manufacturing that minimizes logistics challenges and environmental impact. In energy and biomanufacturing, these decentralized systems are fostering resilient infrastructures that operate efficiently whether independently or as part of an integrated network. This agility in supply chain management not only responds to disruptions but also supports scalable growth in diverse settings.

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#### SUSTAINABILITY & CIRCULARITY: REDUCING WASTE, IMPROVING MATERIAL EFFICIENCY, ENABLING CLOSED-LOOP SYSTEMS

Sustainability is at the heart of modern industrial transformation. Integrating circular economy principles, innovations in recycling, waste-to-value technologies, and eco-friendly design are redefining production cycles. By reducing waste and enhancing material efficiency, companies can lower costs while also minimizing environmental footprints. Closed-loop systems, where end-of-life products are reintegrated as inputs, are setting new benchmarks for sustainability, ensuring that economic growth is balanced with what is now increasingly critical: responsible resource management.

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#### **NEXT-GEN MATERIALS & MANUFACTURING:** HIGH-PERFORMANCE, ADAPTIVE MATERIALS AND BIO-INSPIRED FABRICATION

At the cutting edge of technological progress, next-gen materials and manufacturing processes are rewriting the rules of production. High-performance materials—including quantum and nature-inspired materials—offer properties that far exceed those of traditional substances, unlocking new capabilities in energy, electronics, and beyond. Advanced fabrication techniques, such as 3D printing and nanoscale assembly, enable precise, on-demand customization that minimizes waste. In parallel, scalable bio-based production methods are emerging as vital for sectors ranging from pharmaceuticals to food and chemicals, driving sustainable growth with improved efficiency and reduced environmental impact.

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DEEP DIVE

## Climate Innovation & Sustainable Systems

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## Climate Innovation & Sustainable Systems

Humanity stands at a pivotal moment: addressing climate resilience, resource efficiency, and environmental stewardship has never been more urgent, or laden with economic potential.

Around the globe, rising demand for clean energy, carbon reduction, sustainable agriculture, and circular manufacturing is driving a wave of tangible innovation. Today's climate innovations and sustainable systems aren't just key to an era-defining environmental transformation; they also represent substantial growth opportunities for investors.

Consider climate-resilient agriculture that boosts yields while conserving water, or nextgeneration industrial technologies that capture carbon and optimize resource use. These emerging solutions are both mitigating pressing ecological challenges and reshaping entire markets. Technologies like water purification systems that transform waste streams into valuable resources or green chemistry approaches that reduce the overall environmental burden of petrochemicals and industrial processes—including toxic by-product generation and hazardous waste—move well beyond mere regulatory compliance or corporate social responsibility. Forward-thinking investors recognize that breakthroughs in resource efficiency, water scarcity mitigation, and cleaner industrial processes do more than address systemic risks: they unlock enduring business value.

In this section, we delve into the evolving landscape of hard tech innovation aimed at safeguarding our planet. We highlight the breadth of solutions being developed and the market opportunities that emerge when environmental goals align with commercial success. From advanced waste-to-value platforms to novel methods for mineral processing, these ventures promise not only to drive strong returns for those who finance the technology but also provide significant environmental benefits.

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### **Agriculture & Food Systems:** Meeting Growing Demand Sustainably

Ensuring that a rising global population has reliable access to nutritious food is one of society's most urgent challenges. At the same time, agriculture must adapt to increasing climate pressures and protect finite resources, no small task for an industry already grappling with soil depletion, water scarcity, and volatile market demands. Yet even in the face of these headwinds, a new generation of hard tech innovation is transforming the way we grow, process, and deliver food. By integrating advanced materials, robotics, biological science, and data analytics, these breakthroughs are paving the way for higher productivity, reduced waste, and a significantly lower environmental footprint.

#### PRECISION AGRICULTURE

Sensor-driven monitoring, drone imaging, and automated farm management including controlled environment agriculture such as vertical farming, smart greenhouses, and precise nutrient delivery systems enable farmers to apply water, fertilizers, and pesticides exactly where and when needed. This targeted approach not only reduces input costs and minimizes runoff but also improves crop yields, whether on smallholder farms in emerging markets or in large-scale, tech-enabled operations. These areas of innovation are enabling precision agriculture and revolutionizing how food is produced.

#### **POST-HARVEST & LOGISTICS**

In parallel, innovations in post-harvest and logistics are ensuring that food reaches consumers in optimal condition. Advances in cold chain storage, food safety technology, food preservation, and automated sorting are transforming the way we handle produce after harvest. These technologies minimize waste, maintain quality, and enable more efficient distribution, thereby supporting a more resilient and sustainable food supply chain.

![](_page_16_Picture_22.jpeg)

## Hinalea<sup>®</sup>

Hinalea is redefining industrial optimization for sectors like food manufacturing. The company has developed a state-of-the-art Hyperspectral imaging and AI platform, which leverages deep learning and advanced machine vision to transform raw data into actionable insights. By integrating patented optics with machine-learning-driven analytics, Hinalea enables real-time monitoring and detection to recognize potential issues before they escalate.

Hinalea's solutions can integrate effortlessly into diverse industrial environments—from semiconductor to food manufacturing. This intelligent approach not only optimizes resource use but also drives strategic decision-making, paving the way for a more resilient and responsive operational landscape.

<u>hinalea.ai</u>

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#### **REGENERATIVE AGRICULTURE**

Meanwhile, regenerative agriculture is emerging as a holistic approach to restoring soil health, sequestering carbon, and enhancing farm resilience. Cutting-edge solutions such as microbial fertilizers, novel crop inputs, and farming practices that promote soil carbon sequestration are revitalizing degraded lands and reducing reliance on chemical inputs. By turning farms into carbon sinks and boosting biodiversity, regenerative methods deliver both environmental and economic benefits.

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NewLeaf Symbiotics is a trailblazer in agricultural biotechnology that is redefining sustainable farming through its exclusive focus on Pink-Pigmented Facultative Methylotrophs (PPFMs). By sequencing over 6,500 PPFM strains, NewLeaf has built an unparalleled knowledge base powering a robust pipeline of agricultural solutions. Their journey began with biostimulants that enhance plant vigor and nutrient uptake, proving PPFMs' ability to boost crop resilience under challenging conditions. Building on this success, NewLeaf has expanded into biocontrol with two EPA-registered products: TS601, a biofungicide for soybeans, and TS201, an innovative bioinsecticide. In its first commercial season, TS201 was deployed on nearly 450,000 acres, delivering a remarkable 9 bushel per acre yield advantage by repelling corn rootworm larvae and promoting root regrowth.

Beyond these early wins, NewLeaf is exploring additional frontiers in nitrogen efficiency and methane mitigation, leveraging the natural capabilities of its microbial platform to improve nutrient uptake and reduce greenhouse gas emissions. In doing so, NewLeaf Symbiotics is not only enhancing productivity and crop resilience but also setting new benchmarks for sustainable agriculture by transforming advanced microbiome research into scalable, market-ready solutions.

newleafsym.com

### PRIME ROOTS

Prime Roots is transforming the deli aisle with its mycelium-based meat alternatives that authentically replicate the taste, texture, and protein content of traditional charcuterie—without nitrates, preservatives, soy, or wheat. Founded in 2017 by Berkeley entrepreneurs Kimberlie Le and Joshua Nixon, Prime Roots leverages a proprietary biomass fermentation process to grow fungal mycelium into fibrous, sliceable "meats" (e.g., turkey, ham, salami, bacon) that deliver 90% fewer greenhouse gas emissions, 92% less water use, and dramatically lower land requirements than. By marrying minimal processing with next-generation fermentation, Prime Roots exemplifies hard tech's potential to drive both robust returns and meaningful environmental impact.

#### primeroots.com

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#### **ALTERNATIVE PROTEINS**

Lastly, the rise of alternative proteins represents a bold shift in food production. Innovations in cellular agriculture and fermentation-based protein production are challenging traditional animal agriculture by offering sustainable, resource-efficient alternatives. These breakthrough technologies not only reduce the environmental impact associated with conventional livestock farming but also open new markets for scalable, high-quality protein sources.

Together, these hard tech innovations in agriculture and food systems are reinventing one of the world's oldest industries. Early indicators of success, including improved profitability and higher yields, underscore the scale of the opportunity. And as major agribusinesses seek to secure resilient supply chains, investors have a unique chance to support technologies that deliver competitive returns while enhancing global food security.

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#### AGRICULTURE & FOOD SYSTEMS: SECTOR SNAPSHOT

Metric	Precision Agriculture	Post-Harvest & Logistics	Regenerative Agriculture	Alternative Proteins
Key Metrics	▲ Yield increase (%), water use reduction (m <sup>3</sup> /ha)	Reduction in post-harvest losses (%)	Soil carbon sequestration (t/ha)	Reduction in land and water usage (%)
	Pesticide and fertilizer reduction (%)	<ul> <li>Improved product quality</li> <li>Extended shelf-life (days)</li> </ul>	<ul><li>Reduction in chemical inputs</li><li>Biodiversity restoration</li></ul>	▲ GHG emission savings (%)
<b>ROI Potential</b>	High	Moderate to High	Moderate	High
	Direct cost savings through optimized inputs and higher yields	Efficiency gains in logistics can lower overall supply chain costs	Long-term soil health and carbon credits can drive returns	Rapid market growth as consumer preferences shift to sustainable proteins
Market Readiness	Mature	Maturing Rapidly	Early to Emerging	Early to Emerging
	Proven tech in many markets	Scaling in diverse settings	Pilot projects expanding	Increasing commercial viability
Adoption Barriers	High initial capital Training needs Fragmented rural adoption	Infrastructure costs Regulatory hurdles in food safety	Farmer education Short-term cost challenges Uncertain policy incentives Volatile carbon markets	Cost competitiveness vs. traditional proteins Consumer acceptance Lack of precision fermentation infrastructure for scaling

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## Green Chemistry & Industrial Biology: Pioneering a Sustainable Industrial Transformation

In today's rapidly evolving industrial landscape, traditional processes are under pressure to shift toward more sustainable, resource-efficient methods. Green chemistry and industrial biology are at the forefront of this transformation, offering innovative solutions that reduce environmental impact while creating economic value. This segment of hard tech innovation spans four key areas:

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#### SUSTAINABLE MATERIALS

#### Innovations in sustainable materials are redefining the manufacturing process. Bio-based polymers and biodegradable packaging are just a couple examples of technologies that reduce reliance on fossil fuelderived products. By replacing conventional materials with those derived from renewable sources, companies can significantly lower their carbon footprint and foster a circular economy. These advances not only minimize environmental impact but also deliver cost advantages and unlock new market opportunities as consumer demand increasingly favors greener products.

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#### **CARBON CAPTURE & UTILIZATION**

Addressing the pressing challenge of excess atmospheric carbon, breakthrough technologies in carbon capture and utilization are emerging as powerful tools. Point source carbon capture systems, direct air capture (DAC) systems, carbon mineralization techniques, and synthetic fuel production are transforming CO<sub>2</sub> from a liability into a valuable resource, unlocking a forecasted \$1.2 trillion market opportunity, based on technology-based removals, by 2050<sup>6</sup>. Additionally, bioremediation, using biological processes to restore degraded environments, presents a dual opportunity to clean up industrial sites while capturing carbon. These solutions hold the potential to drive significant returns by converting emissions into marketable products and reducing compliance costs in a carbon-constrained world.

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#### WATER & WASTE TREATMENT

Water is fast becoming one of our most critical resources, and efficient treatment technologies are essential for sustainable industrial operations.

Advances in desalination, wastewater reuse, and closed-loop systems are revolutionizing how industries manage water and waste. Moreover, next-generation treatment processes are increasingly designed to remove persistent pollutants and "forever chemicals", contaminants that linger in the environment for decades and are at the center of intense litigation in markets like the US, thus ensuring both cleaner water and greater regulatory certainty. By integrating these technologies, companies can drastically reduce water consumption, lower operational costs, and minimize environmental impact, thereby strengthening supply chain resilience and contributing to broader sustainability goals.

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#### **REGENERATIVE & NATURE-BASED SOLUTIONS**

**Complementing technological** innovations, regenerative and nature-based approaches offer powerful, scalable solutions for carbon sequestration and ecosystem restoration. Techniques such as soil carbon sequestration and enhanced rock weathering harness natural processes to absorb CO<sub>2</sub> and rejuvenate degraded land. These methods not only help mitigate climate change but also improve soil health, increase biodiversity, and provide long-term economic benefits through sustainable land management practices. Together, these advances in green

chemistry and industrial biology are driving a fundamental shift in how industries operate. They are creating new revenue streams, reducing costs, and opening up substantial market opportunities for investors.

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#### GREEN CHEMISTRY & INDUSTRIAL BIOLOGY: SECTOR SNAPSHOT

Metric	Sustainable Materials	<b>Carbon Capture &amp; Utilization</b>	Water & Waste Treatment	Regenerative & Nature-Based Solutions
Key Metrics	<ul> <li>Reduction in carbon footprint (tons CO<sub>2</sub> avoided)</li> <li>Improved biodegradability</li> <li>Waste reduction (%)</li> </ul>	<ul> <li>CO<sub>2</sub> captured per unit of energy</li> <li>Conversion efficiency</li> <li>Synthetic fuel yield</li> <li>Remediation rate (%)</li> </ul>	<ul> <li>Water savings (m<sup>3</sup>/ha or % reduction)</li> <li>Wastewater quality improvement</li> <li>Waste diversion (%)</li> </ul>	<ul> <li>Soil carbon sequestration (tons/ha)</li> <li>Biodiversity indices</li> </ul>
<b>ROI Potential</b>	Moderate to High Growing demand for bio-based and biodegradable alternatives drives cost savings and new revenue streams	High Converting emissions into marketable products and potential carbon credit revenue bolster returns	Moderate Efficient water management lowers operational costs and mitigates regulatory risks	Moderate to High Long-term asset value through improved land productivity and potential for carbon credits
Market Readiness	Emerging to Mature Several technologies are proven at scale; however, integration across industries remains in progress	Emerging Pilot projects and early commercial deployments are gaining traction	Mature Many water treatment technologies are already deployed, with ongoing improvements in efficiency	Early to Emerging Nature-based approaches are scaling, with increased policy support but variable technical maturity
Adoption Barriers	High initial capital investment Regulatory hurdles Integration challenges with existing manufacturing processes	Significant capital costs Energy intensity concerns Uncertain regulatory frameworks	Infrastructure costs for upgrading legacy systems Variability in water quality standards	Uncertain policy incentives Longer return horizons Challenges in quantifying ecosystem benefits

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## **Energy & Grid Solutions:** Empowering a Resilient Energy Future

Modern energy grids remain largely based on century-old infrastructure, heavily reliant on fossil fuels and vulnerable to supply scarcity and price volatility. As the world increasingly embraces renewable energy, driven by falling costs, technological advances, and pressing environmental imperatives, hard tech innovations in energy and grid solutions become essential not only for integrating clean power but also for modernizing the underlying system to ensure capacity, resilience, and efficiency.

While policy fluctuations and regional setbacks may affect the pace of progress, there is a growing global focus on diversifying fuel sources and reducing the carbon intensity of energy production. This evolution highlights the timely need for advanced technologies that can transform energy networks and bolster our future energy security.

#### **NEXT-GEN BATTERY SYSTEMS**

Advances in battery technology are redefining energy storage and grid reliability. Breakthroughs in flow battery technology promise higher energy densities, improved safety, lower costs, and longer lifespans compared to conventional lithium-ion systems, making them a compelling option for grid-scale energy storage. These next-generation batteries enable the efficient storage of intermittent renewable energy, support grid stabilization during peak demand, and provide backup power for critical infrastructure. By modernizing storage solutions, these technologies help reduce dependence on fossil-fuel-based backup systems and mitigate the impact of fuel price fluctuations.

McKinsey & Company estimates the global battery energy storage systems (BESS) market will reach \$120–\$150 billion per year by 2030, more than double its current size<sup>7</sup>. (This includes utilityscale, commercial, and residential storage, but utility-scale is the largest segment.) Such growth implies a robust double-digit annual revenue expansion for the industry. Bloomberg NEF projects roughly \$262 billion in cumulative investment is needed over 2021-2030 to deploy the forecasted storage capacity (~1 TWh) by 2030<sup>8</sup>. Other analyses likewise foresee multi-billion dollar annual markets, with global energy storage investment and revenue accelerating sharply through the decade.

McKinsey & Company estimates the global battery energy storage systems (BESS) market will reach \$120-\$150 billion per year by 2030, more than double its current size

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#### **ENERGY CONVERSION & POWER MANAGEMENT**

While much of our current grid was built over a century ago, innovations in energy conversion and power management are modernizing these aging networks. Advanced inverters and emerging technologies like superconducting grids have the potential to revolutionize how electricity is converted, transmitted, and distributed. By virtually eliminating energy losses during transmission, these systems can increase grid capacity and enable dynamic power management. The integration of such innovations not only facilitates a smoother transition to renewables but also enhances the grid's resilience and reliability in an era of rising demand and evolving energy sources.

#### HYDROGEN & ALTERNATIVE FUELS

As fossil fuel reserves become increasingly volatile, the energy market is witnessing a surge in alternative fuels and emissions abatement strategies that are reshaping energy systems. Hydrogen is emerging as a versatile energy carrier, with green hydrogen (produced using renewable energy) offering a clean solution for storage and transportation. Meanwhile, breakthrough efforts in methane abatement are reducing emissions from natural gas systems, and renewable natural gas derived from biogas is providing a low-carbon substitute for conventional fossil natural gas. In parallel, synthetic fuels, including ammonia-based carriers and synthetic hydrocarbons, are opening new pathways to decarbonize sectors that are difficult to electrify. Together, these innovations not only complement renewable power generation but also provide stable, scalable energy sources that enhance the overall resilience and diversity of the energy mix.

They enable a more efficient, adaptive, and low-carbon energy network that is less vulnerable to fuel price shocks and resource scarcity. Although barriers to market adoption such as current electrolyzer costs and limited distribution networks (1,600 miles of hydrogen pipelines<sup>9</sup> vs 3 million miles of natural gas pipelines in the US<sup>10</sup>) exist, as regulatory frameworks evolve and investment in renewable capacity grows, these hard tech advancements will offer investors compelling opportunities to back technologies that drive both economic value and a sustainable, secure energy future.

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#### **ENERGY & GRID SOLUTIONS:** SECTOR SNAPSHOT

Metric	Next-Gen Battery Systems	<b>Energy Conversion &amp; Power Management</b>	Hydrogen & Alternative Fuels
Key Metrics	<ul> <li>Improved energy density (Wh/kg), enhanced safety</li> <li>Longer cycle life</li> <li>Increased grid stability</li> </ul>	<ul> <li>Reduction in transmission losses (% reduction)</li> <li>Improved power quality</li> <li>Dynamic grid responsiveness</li> </ul>	<ul> <li>CO<sub>2</sub> reduction per unit of fuel</li> <li>Lower carbon intensity</li> <li>Potential to decarbonize industrial sectors</li> </ul>
ROI Potential	High Direct cost savings through more efficient storage and reliable grid support	High Upgrading legacy infrastructure reduces operational costs and improves system efficiency	High Converting excess emissions into marketable fuels and diversifying energy sources offers strong returns
Market Readiness	Emerging to Mature Several technologies are proven at scale; however, integration across industries remains in progress	Emerging Pilot projects and targeted upgrades are paving the way for broader grid modernization, despite legacy challenges	Mature Green hydrogen and synthetic fuels are scaling, with increasing commercial deployments, but some technologies are still relatively expensive
Adoption Barriers	High capital investment Integration with existing systems Raw material constraints	Legacy infrastructure Regulatory hurdles Significant upfront capital requirements	High capital and production costs Scalability challenges Evolving regulatory frameworks

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### **Circular Economy & Resource Recovery:** Reinventing Resource Lifecycles

As global resource scarcity intensifies and environmental pressures mount, the circular economy offers a transformative pathway to sustainability and profitability. By rethinking resource lifecycles—from extraction to end-of-life—innovative technologies in circular economy and resource recovery are unlocking value in materials once considered waste. This sector spans three critical areas:

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## METAL RECYCLING FROM ELECTRONIC WASTE & URBAN MINING

With electronic waste and urban scrap representing vast, underutilized reservoirs of valuable materials, innovations in metal recycling are revolutionizing the way we reclaim rare-earth elements and other critical metals. Advanced recycling technologies and closed-loop manufacturing processes are enabling the efficient recovery of metals from end of life electronics and other materials, reducing reliance on conventional mining and mitigating the environmental impacts of resource extraction. These breakthroughs not only support environmental stewardship but also offer significant economic benefits by transforming waste into highvalue inputs for manufacturing.

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pH7 Technologies is redefining mineral extraction with its breakthrough solvometallurgical processes. By replacing traditional, energy-intensive smelting with a solvent-based approach, pH7 is able to extract critical and precious metals more sustainably and with a dramatically lower environmental footprint. Their innovative, low temperature technology not only minimizes greenhouse gas emissions and toxic byproducts but also supports a circular economy by recycling valuable materials from waste streams.

This approach positions pH7 as a leader in sustainable mineral processing—a critical component in the global transition toward cleaner, more resource-efficient industries. With robust intellectual property and scalable solutions, pH7 Technologies exemplifies how hard tech innovations can deliver both significant financial returns and meaningful environmental impact, aligning perfectly with Pangaea's mission to drive transformative investments in hard tech.

ph7technologies.com

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#### SUSTAINABLE METAL PROCESSING

Traditional metal processing is energy-intensive and environmentally damaging. In contrast, sustainable metal processing technologies such as hydrometallurgy, biomining/ bioleaching, and electrochemical extraction, are emerging as greener alternatives. These processes use chemical and biological methods to extract metals more efficiently and with lower carbon footprints, reducing both energy consumption and waste generation. By optimizing extraction techniques, companies can lower production costs while minimizing environmental impact, creating a win-win scenario for both business and the planet.

#### SUSTAINABLE MINING & RESOURCE OPTIMIZATION

Beyond recycling and processing, innovations in sustainable mining and resource optimization are redefining how we manage and extract raw materials. Advanced solutions in mine tailings management, circular water treatment and reuse, and enhanced ore recovery with efficient extraction techniques are transforming the mining industry. These technologies not only help mitigate environmental risks such as water contamination and tailings disposal, but also unlock additional value from existing resources. For instance, recovery of co-products during copper extraction can reach up to 20% of primary copper production value<sup>11</sup>. This ensures that every ounce of ore is utilized more efficiently, driving both economic and environmental benefits.

Together, these circular economy innovations are poised to redefine the traditional extraction and production models. They enable industries to recover valuable materials from waste, reduce their environmental footprint, and achieve a more sustainable balance between economic growth and resource conservation. As companies and governments increasingly recognize the dual benefits of environmental stewardship and cost savings, investments in these transformative technologies offer a compelling opportunity for those looking to secure long-term returns in a resource-constrained world. In the chapters ahead, we'll explore these sub-categories in greater detail, examining the technologies driving the circular economy and the investment opportunities they present.

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#### CIRCULAR ECONOMY & RESOURCE RECOVERY: SECTOR SNAPSHOT

Metric	Metal Recycling from E-Waste & Urban Mining	Sustainable Metal Processing	Sustainable Mining & Resource Optimization
Key Metrics	<ul> <li>Recycling efficiency (% of recoverable metals)</li> <li>Reduction in primary resource extraction</li> <li>Carbon footprint reduction</li> </ul>	<ul> <li>Energy intensity (kW/kg metal)</li> <li>Lower emissions per unit produced</li> <li>Yield improvements</li> </ul>	<ul> <li>Increased ore recovery rates (%)</li> <li>Reduction in tailings and waste</li> <li>Water savings (m<sup>3</sup>/ton ore processed)</li> </ul>
ROI Potential	High Valuable materials (e.g., rare-earth elements) recovered from waste can command premium prices; reduced dependency on primary mining drives cost savings	More efficient, lower-impact extraction methods can cut production costs and generate additional revenue through environmental credits	Moderate to High Improved resource utilization and waste minimization can unlock additional value from existing mining operations
Market Readiness	Emerging to Mature Proven technologies exist, but scaling and integration into supply chains remain key challenges	Emerging Several pilot projects are in place, with early commercial deployments beginning to gain traction	Early to Emerging Ongoing innovations and regulatory pressures are driving early adoption; full market maturity is still on the horizon
Adoption Barriers	High capital investment Fragmented waste streams Regulatory hurdles Integration challenges with existing manufacturing processes	Technical complexity Significant upfront investment Resistance from established processes	Legacy mining infrastructure Regulatory uncertainty The need for substantial retrofitting to adopt new processes

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#### SECTION WRAP UP

### **Pangaea's Partners Perspective:**

The intersection of critical metals recovery and materials circularity is vital to addressing both geopolitical supply risks and environmental challenges in electrification. By advancing efficient recovery technologies, innovators can reduce reliance on volatile international supply chains, lower the carbon footprint of extraction, and transform waste streams into value-generating resources.

Beyond metals, improvements in emissions reductions and process efficiency directly correlate to enhanced resource utilization and value creation. Every molecule lost in traditional processes represents not just a missed economic opportunity but a failure to align with planetary health imperatives. This underscores our commitment to innovations that maximize resource utilization while slashing emissions.

Sarah Applebaum, Partner

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DEEP DIVE

## Computational & Physical Infrastructure

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## Computational & Physical Infrastructure

### In today's rapidly evolving technological landscape, robust computational and physical infrastructures form the backbone of innovation across multiple industries.

As digital transformation accelerates, the demand for breakthroughs in semiconductor design, advanced manufacturing processes, and integrated discovery platforms has never been more pronounced.

These foundational technologies are not merely enabling incremental improvements—they are redefining the parameters of what's possible, unlocking powerful competitive advantages, improving national security and creating vast economic potential for investors willing to lead the charge.

Take, for example, the strides being made in semiconductor technology, which are propelling everything from high-performance computing to artificial intelligence; or consider advanced manufacturing and materials that are reinventing production processes, driving efficiencies that reshape entire supply chains. Meanwhile, computational discovery platforms are revolutionizing research and development by harnessing data at unprecedented scales, and biological infrastructure and manufacturing are setting the stage for a new era in biotech innovation. Each of these sub-categories represents a critical lever in the broader hard tech ecosystem—one where digital and physical realms converge to forge new frontiers in productivity, quality, and scalability.

This section delves into the transformative landscape of computational and physical infrastructure, spotlighting the innovations that underpin modern industry. As global markets increasingly recognize that sustained competitive advantage stems from strategic investment in these core technologies, investors are poised to benefit from early participation in platforms that offer robust, enduring value. From the intricacies of chip design to the integration of advanced materials in manufacturing, the areas of innovation that we explore in this category are not only the engine behind technological progress—they will become the drivers of economic growth and industrial resilience.

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### **Semiconductors:** Powering the Next Generation of Compute Innovation

As the digital age accelerates, semiconductors are emerging as the linchpin of technological evolution, driving both performance and efficiency to new heights. Within this arena, two interrelated domains are setting the stage for transformative breakthroughs: Next-Gen Compute Materials & Architectures and Advanced Chip Manufacturing & Integration. Together, they are redefining what's possible in computing, enabling unprecedented speed, power, and scalability.

#### **NEXT-GEN COMPUTE MATERIALS & ARCHITECTURES**

Innovations in semiconductor materials and computing paradigms are forging a new path forward. Cutting-edge materials like gallium nitride (GaN), silicon carbide (SiC), phase-change memory, and resistive RAM (ReRAM) are challenging the dominance of traditional silicon, offering superior energy efficiency, thermal performance, and durability. Simultaneously, novel compute architectures, ranging from photonic computing to optical processors, are paving the way for faster, more efficient data processing. By transcending the limits of conventional semiconductor physics, these advancements not only enhance processing capabilities but also unlock new market opportunities for applications in AI, high-performance computing, and beyond.

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#### **ADVANCED CHIP MANUFACTURING & INTEGRATION**

At the heart of semiconductor innovation lies the art and science of chip fabrication and integration. Revolutionary techniques such as EUV lithography and nanosheet transistor design are pushing the boundaries of miniaturization, enabling manufacturers to pack more power into smaller, more efficient chips. In tandem, chiplet-based architectures and state-of-the-art packaging solutions are transforming how components are interconnected, significantly boosting performance while reducing energy consumption. These manufacturing breakthroughs are critical not only for maintaining Moore's Law in an era of escalating computational demands but also for fostering a more resilient and adaptable hardware ecosystem that can meet the needs of tomorrow's digital world.

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ChEmpower is reinventing a core semiconductor manufacturing process with its patented, abrasive-free planarization technology. By replacing both slurry and traditional pads with a single chemistry-empowered polymer pad, ChEmpower eliminates particle defects, reduces wastewater, and increases chip yields—directly addressing the billion-dollar cost of yield loss at advanced nodes. Designed as a drop-in solution for existing CMP tools, the company's platform requires no equipment changes and delivers up to 50% lower total cost of ownership compared to legacy consumables. With robust IP covering both chemistry and pad design, and a clear path to scale, ChEmpower exemplifies hard tech's power to drive sustainable, high-impact innovation in advanced manufacturing.

chempower-corp.com

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#### SEMICONDUCTORS: SECTOR SNAPSHOT

Metric	Next-Gen Compute Materials & Architectures	Advanced Chip Manufacturing & Integration
Key Metrics	Breakthroughs in novel materials (GaN, SiC, phase-change memory, ReRAM) and compute paradigms (photonic, optical processors) that drive energy efficiency, thermal performance, and exponential compute speed improvements	Fabrication advancements (EUV lithography, nanosheet transistors) and chiplet-based architectures that enhance chip density, yield, and overall performance while reducing power consumption and production costs
<b>ROI</b> Potential	High	High
	Novel materials and compute architectures enable new performance frontiers in AI and HPC, translating into premium pricing and strong early mover advantages for breakthrough technologies	Advanced manufacturing and integration innovations offer direct cost reductions, yield improvements, and competitive differentiation, driving substantial long-term returns for investors as production scales
Market Readiness	Early to Emerging	Emerging to Mature
	Many technologies are in pilot or validation phases; while promising, further testing and commercial scale-up are required before widespread adoption	Several fabrication breakthroughs and packaging innovations have begun to see commercial traction, though scaling and supply chain optimization remain critical for achieving full market potential
Adoption	High R&D investment and technical risk	Significant CAPEX requirements
Barriers	Integration challenges into existing design flows	Complex manufacturing ecosystems
	Need for robust intellectual property protection to secure competitive	The need to align with evolving industry standards
	advantage	Supply chain constraints
		High technical expertise

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### Advanced Manufacturing & Materials: Redefining Production and Material Innovation

At the frontier of industrial transformation, advanced manufacturing and materials technologies are reshaping how products are designed, produced, and optimized. This sector is a hotbed of innovation, where breakthroughs in additive manufacturing, robotics, and novel materials are converging to create production systems that are more agile, efficient, and adaptable than ever before.

#### **3D PRINTING & ADDITIVE MANUFACTURING**

Additive manufacturing is breaking away from traditional production constraints by enabling the precise fabrication of complex geometries across a range of materials—from metals and ceramics to composites and bio-based substances. This technology not only reduces waste and shortens production cycles but also unlocks design possibilities that were once impractical. The ability to customize products on demand is creating new revenue streams and cost efficiencies across sectors, from aerospace to healthcare.

#### INDUSTRIAL ROBOTICS & AUTOMATION

The next wave in manufacturing is being powered by advancements in robotics and automation. Innovations such as soft robotics, integrated sensor networks, and specialized end effectors are enhancing the dexterity and responsiveness of automated systems. These technologies are critical for increasing operational efficiency, reducing labor-intensive processes, and ensuring high levels of precision. As industrial robots become more adaptable and intelligent, they are setting the stage for a new era of scalable, smart production environments.

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#### **QUANTUM & EXOTIC MATERIALS**

Beyond conventional materials, the exploration of quantum and exotic substances is opening up transformative avenues for manufacturing. High-temperature superconductors, metamaterials, and programmable matter represent a paradigm shift in material science. These innovations promise to deliver unprecedented properties—such as ultra-high conductivity, unique optical characteristics, or adaptive functionalities. For example, research by the Electric Power Research Institute (EPRI) indicates that superconducting DC cables can transmit 5x more power than conventional cables of similar size, with line losses 50-70% lower than overhead AC/DC systems<sup>12</sup>. Although proving the utility of these materials can require extensive R&D, there may be specific practical applications that can fundamentally alter performance benchmarks in everything from electronics to structural engineering.

Together, these innovations in advanced manufacturing and materials are not just optimizing existing production processes—they are reinventing the very foundation of industrial operations. As these technologies mature, they promise to deliver significant improvements in efficiency and product quality, providing investors with a compelling opportunity to capitalize on the next wave of industrial revolution.

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#### ADVANCED MANUFACTURING & MATERIALS: SECTOR SNAPSHOT

Metric	<b>3D Printing &amp; Additive Manufacturing</b>
Key Metrics	<ul> <li>Production speed</li> <li>Material utilization efficiency</li> <li>Design complexity</li> </ul>
ROI Potential	High Lower tooling costs and on-demand manufacturing create strong margins, especially in sectors like aerospace, healthcare, and automotive
Market Readiness	Emerging to Mature Rapidly growing adoption across industries, though scaling to high-volume production remains a key challenge for some applications
Adoption Barriers	Material consistency High initial capital investment Integration with legacy manufacturing systems can slow widespread adoption

Industrial Robotics & Automation	Quantum & Exotic Materials
<ul> <li>Cycle time</li> <li>Operational uptime</li> <li>Labor cost savings</li> </ul>	<ul> <li>Performance improvements</li> <li>Breakthrough material properties</li> </ul>
High	Moderate to High
Streamlined operations and increased	While still emerging, early adoption in
automation yield significant cost reductions	niche high-performance markets can yield
and scalability, translating into robust, long-	disruptive advantages and premium pricing
term financial returns	on novel applications
Emerging to Mature	Early
Broad adoption in many industrial settings,	Largely in the R&D and pilot phases; market
with ongoing innovations improving	penetration is limited but holds strong
adaptability and integration across varied	potential as technological breakthroughs
production environments	advance
Significant CAPEX	High R&D costs
The need for skilled workforce training	Technical risk, and scalability issues
Complex integration with existing production	coupled with regulatory uncertainties
lines pose challenges to seamless	present substantial hurdles for commercial
implementation	deployment

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### **Computational Discovery Platforms:** Accelerating Breakthroughs in R&D

In an era defined by data and precision, computational discovery platforms are reshaping the way industries approach research and development. At the forefront of this transformation is the application of artificial intelligence in materials development and drug discovery. By harnessing advanced machine-learning algorithms and quantum chemistry simulations, this innovative sub-sector is streamlining the path from concept to market-ready solution, radically reducing both development time and cost. For example, PwC reports that AI-driven computational discovery platforms have already helped many pharmaceutical companies reduce drug discovery timelines by over 50%, and estimates that broader implementation in R&D could cut time-to-market by up to 50% and lower costs by as much as 30% in sectors such as automotive and aerospace<sup>13</sup>.

#### **AI FOR MATERIALS & DRUG DISCOVERY**

Machine learning is redefining traditional R&D paradigms by analyzing vast datasets to predict material properties and drug efficacy with unprecedented accuracy. Quantum chemistry simulations further enhance these capabilities, allowing researchers to model complex molecular interactions and reaction pathways at an atomic level. Together, these technologies enable the rapid identification of promising compounds and materials that might otherwise take years to discover through conventional experimentation. This acceleration not only paves the way for next-generation therapeutics and high-performance materials but also offers investors an opportunity to tap into markets poised for disruption and growth.

By integrating AI-driven insights with sophisticated simulation tools, computational discovery platforms are breaking down barriers in innovation, delivering tangible benefits in efficiency, cost, and scalability.

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#### COMPUTATIONAL DISCOVERY PLATFORMS: SECTOR SNAPSHOT

Metric	AI for Materials & Drug Discovery
Key Metrics	<ul> <li>Increased hit rates in compound/material so</li> <li>Reduced iteration cycles</li> <li>Quantifiable improvements in predictive action</li> </ul>
<b>ROI Potential</b>	High
	By slashing R&D timelines and costs, Al-driver commercialization of novel drugs and material competitive advantages and premium returns pharmaceuticals and advanced materials
Market	Early to Emerging
Readiness	
	While initial pilot projects and strategic partne commercial adoption will depend on overcom challenges and refining model accuracy acros
Adoption Barriers	Technical complexity Reliance on high-quality, extensive datasets, a talent to integrate and interpret machine-learn outputs within traditional R&D frameworks Regulatory uncertainties and risk-averse indus
	widespread uptake

creening

ccuracy for molecular properties

en platforms enable faster als, offering significant s in high-stakes industries like

erships are underway, broad ning technical integration ss diverse datasets

and the need for specialized ning and quantum simulation

stry mindsets may slow

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## **Biological Infrastructure & Manufacturing:** Engineering Nature for a Sustainable Future

Scientists are harnessing the power of biology to revolutionize how we produce materials, fuels, and chemicals by merging engineering with natural processes. Biological infrastructure and manufacturing leverage cutting-edge biotechnologies to create sustainable, scalable solutions that unlock environmental and economic opportunities.

![](_page_37_Picture_17.jpeg)

#### **SYNTHETIC BIOLOGY & ENGINEERED MICROBES**

Innovations in synthetic biology are redefining traditional manufacturing by transforming living cells into versatile production platforms. Engineered microbes are being optimized through microbial metabolic engineering to produce high-value chemicals, pharmaceutical compounds, and industrial enzymes. This approach promises to drastically reduce reliance on fossil-derived processes, offering more sustainable and efficient production routes.

![](_page_37_Picture_20.jpeg)

The development of bio-based materials and polymers is paving the way for a future where producing products that are not only high-performing but also environmentally benign. From biodegradable plastics to advanced bio-composites, these innovations are set to replace conventional materials with alternatives that reduce waste and lower the carbon footprint. Such materials hold the potential to revolutionize industries ranging from packaging to construction, combining functionality with ecological responsibility.

#### **BIO-BASED MATERIALS & POLYMERS**

![](_page_37_Picture_25.jpeg)

#### **BIOFUELS & CARBON-NEGATIVE CHEMISTRY**

Biological pathways are also being harnessed to produce renewable fuels and facilitate carbon-negative chemical processes. By utilizing renewable feedstocks and innovative enzymatic pathways, biofuels offer a sustainable alternative to traditional energy sources. Simultaneously, carbon-negative chemistry transforms CO<sub>2</sub>, methane, or other hydrocarbons into valuable products, turning a greenhouse gas liability into an economic asset while contributing to overall carbon reduction goals. Estimates vary, however recent industry reports suggest CO<sub>2</sub>-derived products and utilization could generate between \$240 billion (by 2045) and \$255 billion (by 2040) in market value, underscoring the significant economic potential of these technologies <sup>14, 15</sup>. The scientific breakthroughs occurring across this sector form a dynamic ecosystem that is not only reshaping manufacturing but also setting the stage for a more sustainable industrial paradigm.

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#### **BIOLOGICAL INFRASTRUCTURE & MANUFACTURING:** SECTOR SNAPSHOT

Metric	Synthetic Biology & Engineered Microbes	<b>Bio-Based Materials &amp; Polymers</b>	<b>Biofuels &amp; Carbon-Negative Chemistry</b>
Key Metrics	Efficiency and yield improvements in bioproduction processes	Environmental benefits through reduced reliance on fossil feedstocks	Conversion efficiency of renewable feedstocks
	Reduced resource usage	Lower lifecycle carbon emissions	Measurable CO <sub>2</sub> utilization or sequestration
	Lower carbon footprints via optimized cell factories and metabolic pathways	Enhanced material performance (e.g., biodegradability and strength)	Quantifiable improvements in fuel yield and process sustainability
<b>ROI Potential</b>	High	Moderate to High	High
	Disruptive advances in engineered biology can drive premium pricing, unlock new market segments, and deliver strong returns through cost-effective, scalable production methods	Streamlined operations and increased automation yield significant cost reductions and scalability, translating into robust, long- term financial returns	While still emerging, early adoption in niche high-performance markets can yield disruptive advantages and premium pricing on novel applications
Market Readiness	<b>Early to Emerging</b> Significant R&D and pilot projects are underway, with promising results but requiring further scale-up and regulatory validation for broader adoption	Emerging to Mature Several applications have reached commercialization, though widespread industry adoption depends on cost competitiveness and performance parity with conventional materials	Early to Emerging While technical proof-of-concept is established, market penetration is contingent on overcoming infrastructural and regulatory hurdles, alongside feedstock availability
Adoption Barriers	Complex R&D, scale-up challenges Regulatory approval processes The need for robust intellectual property protection can slow rapid market penetration	High initial production costs Integration challenges with existing manufacturing systems Performance limitations in some applications may impede rapid uptake	High CAPEX requirements Regulatory uncertainty Infrastructure constraints Variability in renewable feedstock supply poses

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#### SECTION WRAP UP

### **Pangaea's Partners Perspective:**

Global interest in advanced compute and manufacturing has never been greater. Trillions of dollars are going into semiconductor manufacturing for AI and national security. And while there is a lot of money being thrown around, the challenge is to find start-ups in this space solving fundamental problems that don't require billions of dollars.

The current wave of advanced compute and advanced manufacturing is in semiconductors and AI. The second wave is advanced robotics. And the third wave will be drug discovery and other bio-based solutions where AI can quickly discover and solve biological problems like disease, food production and biobased renewable energy. Across all three waves, there is and will be immense opportunity for hard tech founders and investors to unlock transformative value.

Chris Erickson, Partner

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DEEP DIVE

## Human Health & Bioengineering

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## Human Health & Bioengineering

### As we stand on the cusp of a new era in medicine, the convergence of engineering and biology is unlocking unprecedented opportunities in human health.

Capital is flowing into Human Health & Bioengineering, with one estimate from McKinsey proposing that direct annual global potential impact could reach US\$1.3 trillion over the next 10 to 20 years<sup>16</sup>. This capital is not for incremental improvements—but for breakthroughs that enable us to reimagine the future of healthcare. The innovations explored here are poised to revolutionize how diseases are diagnosed, treated, and prevented, with transformative implications for patient outcomes and market growth.

Next-generation imaging hardware, point-of-care diagnostics, and real-time disease detection are redefining clinical decision-making. These breakthroughs are enhancing accuracy, speed, and accessibility in medical testing, empowering clinicians with the tools they need for earlier and more precise interventions.

By harnessing the power of 3D bioprinting, stem cell and gene therapies, and advanced wound healing techniques, regenerative medicine is forging new pathways to curative health and elimination of disease. This field is redefining recovery and quality of life, offering personalized, restorative treatments that were once the realm of science fiction.

At the intersection of data science and biology, advances in long-read sequencing, Al-driven predictive genomics, and CRISPR-based gene editing are paving the way for truly personalized medicine. These innovations not only promise to accelerate the discovery of targeted therapies but as the prices of these technologies come down to achieve tailored interventions to individual genetic profiles, enhancing efficacy and reducing adverse effects.

In this chapter, we delve into the transformative landscape of Human Health & Bioengineering. We examine how these disruptive technologies are reshaping healthcare paradigms, from precise diagnostics to personalized treatments, and creating compelling investment opportunities that bridge the gap between technological potential and tangible patient impact.

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## **Preventative Care & Diagnostics:** Revolutionizing Patient Insight and Intervention

In an era where early and precise detection can redefine treatment trajectories, advances in preventative care and diagnostics are transforming the clinical landscape. This domain is pioneering a shift from reactive to proactive care, leveraging cutting-edge hardware and portable diagnostic tools to capture critical health data at unprecedented speed and clarity. By harnessing state-of-the-art imaging modalities and innovative real-time detection methods, clinicians are equipped to make faster, more informed decisions—ushering in a new paradigm of patient-centered care.

#### NEXT-GEN IMAGING

Emerging modalities such as photon-counting CT, spectral MRI, and AI-powered ultrasound are revolutionizing image quality and diagnostic confidence. These technologies offer unprecedented resolution, enhanced tissue differentiation, and rapid data processing, enabling clinicians to detect subtle pathologies that were previously elusive. This leap in imaging capabilities, some of which have been shown to yield 10x more information and an 80% decrease in radiation dose<sup>17</sup>, supports more timely, safe, and cost-effective interventions, potentially reducing the need for invasive diagnostic procedures.

17. https://www.redlen.com/technology

![](_page_42_Picture_20.jpeg)

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(exited - acquired by Canon Inc)

Redlen Technologies is the world's only merchant supplier of clinical-grade photon-counting CT detectors, powering next-generation imaging with its proprietary Cadmium Zinc Telluride (CZT) sensor modules. By capturing individual X-ray photons and resolving their energy, Redlen's vertically integrated CZT detectors deliver up to 10× finer spatial resolution, 80% lower radiation dose, and multi-energy discrimination—enabling material-specific imaging and Al-driven diagnostics across CT, nuclear medicine, and non-destructive testing applications. Redlen's end-to-end CZT production process overcomes traditional limitations in crystal growth and charge collection, yielding high-performance sensors at scale. Acquired by Canon Inc. in September 2021 for US\$335 million, Redlen's technology is now being integrated into Canon's manufacturing platform to accelerate global deployment. An early investment by Pangaea Ventures, Redlen exemplifies hard tech's ability to transform healthcare outcomes while delivering substantial financial returns.

redlen.com

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#### POINT OF CARE DIAGNOSTICS

Advances in wearable biosensors and microfluidic lab-on-a-chip devices are bringing sophisticated diagnostic tools directly to the patient. These portable, easy-to-use platforms provide rapid insights into a patient's health status, facilitating immediate clinical decision-making and preventative interventions. By decentralizing diagnostic testing from traditional laboratory settings, these innovations increase accessibility and convenience, particularly in resource-limited or remote environments.

#### **MICROBIOME INNOVATIONS & THERAPEUTICS**

In parallel with advances in imaging and point-of-care diagnostics, the burgeoning field of microbiome science is emerging as a true game-changer in healthcare. New computational biology methods, high-throughput sequencing, and machine learning are unraveling the complexities of the human microbiome—our community of trillions of microbes. This deep insight is driving the development of microbiomebased diagnostics, therapeutics, and personalized nutrition strategies that target conditions ranging from metabolic disorders to autoimmune diseases. These investments are fueling breakthroughs such as next-generation probiotics, targeted bacteriophage therapies, and microbiome editing platforms that promise to transform treatment paradigms. By harnessing these innovations, hard tech companies are not only setting the stage for a new era in personalized medicine they are creating compelling opportunities for investors to capitalize on one of the most exciting frontiers in healthcare connecting the gut brain axis to cure what even the newest therapeutics can not touch.

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#### **PREVENTATIVE CARE & DIAGNOSTICS:** SECTOR SNAPSHOT

Metric	Next-Gen Imaging
Key Metrics	<ul> <li>Enhanced imaging resolution</li> <li>Faster scan times</li> <li>Improved diagnostic accuracy that enables earlier disease detection and better patient outcomes</li> </ul>
ROI Potential	High Premium imaging systems command strong pricing in hospitals and specialty centers, with advanced capabilities leading to improved clinical outcomes and operational efficiencies

Point of Care Diagnostics	<b>Microbiome Innovations &amp; Therapeutics</b>	
Rapid, decentralized testing with high sensitivity and specificity	New treatment pathways for chronic, often intractable conditions	
Facilitating immediate clinical decision-making	Improved outcomes while reducing over- treatment.	
Reducing diagnostic turnaround times	Reducing reliance on broad-spectrum antibiotics and helping address global antimicrobial resistance (AMR)	
	Reducing downstream costs by improving early detection, treatment response, and long-term management of chronic disease	
High	High (Long-Term)	
Scalable, portable diagnostic devices can disrupt traditional laboratory testing models, unlocking new revenue streams in diverse care settings and reducing costs	There is growing demand for precision therapies and functional health solutions, strategic opportunities in high-margin areas such as biotherapeutics, next-gen probiotics, and companion diagnostics, and potential for pharma partnerships and subscription-based health platforms	

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#### **PREVENTATIVE CARE & DIAGNOSTICS:** SECTOR SNAPSHOT

Metric	Next-Gen Imaging
Market Readiness	Emerging to Mature Many technologies are in pilot or validation phases; while promising, further testing and commercial scale-up are required before widespread adoption
Adoption Barriers	High CAPEX Regulatory approval challenges Integration with existing hospital systems can slow deployment despite clear clinical advantages

#### **Point of Care Diagnostics**

#### Emerging

Several fabrication breakthroughs and packaging innovations have begun to see commercial traction, though scaling and supply chain optimization remain critical for achieving full market potential

#### **Microbiome Innovations & Therapeutics**

#### **Early to Emerging**

There have been rapid advancements in microbiome sequencing, data analytics, and delivery platforms. Clinical trials are underway and select early products (e.g. FMT, targeted probiotics) are already commercialized. Regulatory clarity is evolving, particularly for live biotherapeutic products (LBPs) and engineered microbial interventions.

Integration with established healthcare workflows

Data security and privacy concerns

Compliance with strict regulatory standards may impede rapid scale-up

Biological complexity and variability across individuals challenge reproducibility

Lack of regulatory frameworks and standardization for microbiome-based therapies

Need for long-term clinical validation and integration into care pathways

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### **Regenerative Medicine & Bioprinting:** Redefining Healing Through Innovation

Advancements in regenerative medicine and bioprinting are charting new territory in the realm of tissue and organ repair. This field harnesses precise manufacturing techniques and cutting-edge biological interventions to address critical health challenges, moving beyond traditional treatments toward solutions that restore and regenerate damaged tissues.

#### **3D BIOPRINTING FOR ORGAN & TISSUE ENGINEERING**

Innovative bioprinting technologies are now capable of fabricating complex structures such as printed cartilage, organ scaffolds, and vascularized tissues. By layering living cells and biomaterials in precise patterns, 3D bioprinting enables the creation of constructs that closely mimic natural tissue architecture. This approach not only promises to bridge the gap between organ shortage and transplant needs but also offers a controlled environment for studying tissue regeneration and human tissues in vitro for more biologically relevant models in drug discovery and testing.

![](_page_46_Picture_19.jpeg)

Aspect Biosystems is redefining regenerative medicine with its full-stack tissue therapeutic platform a proprietary bioprinting system that assembles living cells, biomaterials, and bioactive factors into implantable tissues designed to replace, repair, or supplement biological function. Backed by over US\$260 million in total investment, Aspect has secured a US\$2.6 billion partnership with Novo Nordisk, and government co-funding agreements totaling CA\$200 million to advance therapies for diabetes, obesity, and liver disease. Its technology integrates computational design, scalable manufacturing, and immune-protective biomaterials to deliver clinically relevant tissue candidates—moving beyond preclinical proof-of-concept into planned first-in-human trials. With robust intellectual property covering both hardware and bioprinting processes, Aspect exemplifies hard tech's capacity to translate cutting-edge science into high-margin, high-impact treatments that address urgent global health challenges.

aspectbiosystems.com

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#### **STEM CELL & GENE THERAPIES**

Stem cell therapies are revolutionizing regenerative medicine by restoring function and repairing damaged tissues and organs through the cultivation and transplantation of patient-specific cells. In parallel, gene therapy approaches enhance these regenerative strategies by modulating cellular behavior and promoting tissue repair. (More on advanced gene editing techniques in the next section.) Together, these approaches are driving the development of highly targeted, personalized interventions that hold the promise of dramatically improving recovery outcomes and addressing areas of medicine that have previously been unreachable by conventional therapeutics.

#### WOUND HEALING & TISSUE REPAIR

The integration of smart bandages and bioengineered skin grafts is revolutionizing wound care and tissue repair. These innovative solutions combine responsive materials with biological cues to accelerate the healing process, minimize scarring, and restore functionality. By incorporating sensors and bioactive compounds, smart bandages not only monitor wound conditions in real time but also deliver therapeutic agents directly to the injury site, enhancing the overall repair process.

Together, these hard tech sub-sectors are advancing the frontier of regenerative medicine, enabling the creation of treatments that actively restore function and improve quality of life.

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#### **REGENERATIVE MEDICINE & BIOPRINTING:** SECTOR SNAPSHOT

Metric	3D Bioprinting for Organ & Tissue Engineering	Stem Cell & Gene Therapies	Wound Healing & Tissue Repair
Key Metrics	<ul> <li>Tissue viability</li> <li>Functional integration</li> <li>Scalability</li> </ul>	<ul> <li>Therapeutic efficacy</li> <li>Genetic correction accuracy</li> <li>Patient recovery metrics</li> <li>Cost of manufacturing</li> </ul>	<ul> <li>Reduction in healing time</li> <li>Improved graft integration</li> <li>Patient outcome improvements</li> </ul>
ROI Potential	High Scalable production of functional tissues can address critical organ shortages and command premium pricing, offering early mover advantages in a high-demand market	High Breakthroughs in personalized regenerative treatments have the potential to revolutionize patient care, driving significant reimbursement and market differentiation	Moderate to High Enhanced healing and reduced complications can lower overall healthcare costs, though market returns depend on successful clinical validation and integration into care protocols
Market Readiness	Early to Emerging Scalable production of functional tissues can address critical organ shortages and command premium pricing, offering early mover advantages in a high-demand market	Emerging to Mature Several therapies have reached clinical trials and limited approvals, although broader adoption awaits further regulatory clearance and long-term efficacy data	Mature Numerous early-stage innovations show potential, with ongoing clinical trials and evolving reimbursement models guiding the pace of market adoption
Adoption Barriers	High complexity in scaling tissue fabrication Stringent regulatory pathways Scalable care delivery Challenges in replicating full organ functionality present significant obstacles	Significant R&D investment Regulatory uncertainties Manufacturing and transportation complexities Ethical considerations around personalized therapies may impede rapid uptake	Integration into standard care protocols Regulatory clearance Reimbursement challenges Ensuring consistent manufacturing quality poses challenges to widespread implementation

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## **Genomics & Personalized Medicine:** Redefining Biological Insights for Tailored Therapies

Advances in genomics are rewriting the blueprint of medicine by offering unprecedented insight into individual genetic profiles. This sub-sector harnesses breakthroughs in sequencing, predictive analytics, and gene editing to craft more precise, personalized approaches to healthcare.

![](_page_49_Picture_17.jpeg)

#### LONG-READ & ULTRA-FAST SEQUENCING

Innovative sequencing technologies, including nanopore and single-molecule real-time (SMRT) sequencing, are revolutionizing the speed and accuracy of genomic analysis –with multiple technologies demonstrating 99.9% accuracy, and whole-genome sequencing costs dropping from US\$1 million in 2007 and now approaching \$200. These methods provide longer read lengths and rapid processing capabilities, enabling the comprehensive mapping of complex genetic structures. Such depth of analysis paves the way for more detailed disease profiling and supports the development of targeted interventions.

![](_page_49_Picture_20.jpeg)

#### **AI & PREDICTIVE GENOMICS**

Integrating AI with genomics transforms raw genetic data into actionable insights. Techniques such as digital twin disease modeling and polygenic risk scoring allow for the simulation of disease progression and risk assessment based on a multitude of genetic factors. This data-driven approach helps clinicians anticipate health challenges before they manifest, paving the way for proactive, individualized treatment plans.

![](_page_49_Picture_23.jpeg)

#### **CRISPR & ADVANCED GENE EDITING**

Cutting-edge gene editing technologies, including base editing, prime editing, and synthetic genomics, are setting new standards in the precision correction of genetic anomalies. These advanced tools enable modifications at the molecular level with remarkable specificity, offering the potential to not only treat but also prevent a wide range of genetic disorders. This represents a fundamental shift from traditional therapies toward a more proactive, curative model of care.

Together, these innovations are propelling the field of genomics toward a future where treatments are as unique as the patients themselves, enabling healthcare strategies that are both predictive and precisely targeted.

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#### GENOMICS & PERSONALIZED MEDICINE: SECTOR SNAPSHOT

Metric	Long-Read & Ultra-Fast Sequencing
Key Metrics	Number of bases or genomes sequenced per run or per unit time
	% improvement of accurate reads
	Cost per base or cost per genome sequenced
	Turnaround time from sample input to actionable data output
<b>ROI Potential</b>	High
	Enhanced sequencing capabilities can drive significant efficiencies in research and diagnostics, leading to premium pricing in clinical and research markets

AI & Predictive Genomics	<b>CRISPR &amp; Advanced Gene Editing</b>
<ul> <li>Improved AUC (Area Under the Curve) or precision-recall values that quantify how well models predict outcomes</li> <li>Reduction in the time required to translate raw genomic data into actionable clinical insights</li> <li>The ability of platforms to process increasing volumes of genomic data without loss in performance</li> </ul>	<ul> <li>Percentage of target cells successfully edited in a controlled setting</li> <li>Reduction in frequency or rate of unintended genomic modifications</li> <li>Improvements in patient outcomes in early clinical trials (e.g., success rates in correcting genetic disorders)</li> <li>Duration from experimental proof-of-concept to measurable clinical benefit</li> </ul>
High	High

Data-driven predictive models reduce trialand-error in treatment, improving clinical outcomes and creating scalable platforms with strong recurring revenue potential Revolutionary gene editing techniques promise transformative therapeutic outcomes, potentially commanding high value in personalized treatments and creating new revenue streams in biotech

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#### GENOMICS & PERSONALIZED MEDICINE: SECTOR SNAPSHOT

Metric	Long-Read & Ultra-Fast Sequencing	AI & Predictive Genomics	<b>CRISPR &amp; Advanced Gene Editing</b>
Market Readiness	Emerging to Mature Technologies like nanopore and SMRT sequencing have achieved early commercial success, with ongoing innovation aimed at further reducing costs and increasing throughput	Early to Emerging While several pilot projects and proof-of- concept studies are promising, widespread clinical integration awaits further validation and regulatory clearance	Emerging Many advanced gene editing platforms are in clinical trial stages or early regulatory review, with broad market adoption contingent on long-term efficacy and safety outcomes
Adoption Barriers	High initial capital investments Data management challenges The need for ongoing improvements in accuracy and throughput may slow widespread clinical deployment	Integration challenges with legacy clinical workflows Data privacy concerns The need for standardized methodologies can impede rapid adoption across healthcare systems	Regulatory hurdles Ethical concerns The high technical complexity of achieving precise gene modifications present significant challenges to broad market acceptance and clinical scalability

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### **Pangaea's Partners Perspective:**

Healthcare innovation has been focused on achieving the triple bottom line - reduce cost, improve care and increase access. A new paradigm that biology, computational power, and hard tech have given us is the potential to leverage technology to be curative. We have the potential to eradicate life long diseases, expand treatment efficacy to the once untreatable, and to not only prevent but predict the onset of health decline, working with the body instead of against it to heal.

With the ability to decentralize testing, harness design tools to turn data sets into personalized treatments and democratize biological manufacturing, we are entering an era where biology is not just a subject of study but a tool accessible to everyone everywhere.

Janelle Goulard, Partner

![](_page_52_Picture_20.jpeg)

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## Regional Differences in Hard Tech Innovation

Hard tech innovation does not occur in a vacuum—its evolution is deeply influenced by regional factors such as government policies, resource availability, industrial heritage, and local ecosystems. Understanding these regional dynamics can help investors pinpoint opportunities and manage risks more effectively.

#### NORTH AMERICA

Innovation Ecosystem: The U.S. remains a global leader in R&D, benefiting from a vibrant network of universities, established tech hubs (e.g., Silicon Valley, Boston, Austin), and robust venture capital support.

Focus Areas: Advanced semiconductor design, biotechnology, clean energy solutions, and Al-integrated hardware are major themes, underpinned by strong intellectual property protections and dynamic public-private partnerships.

Government Support: Policy initiatives—like the U.S. CHIPS Act—are accelerating domestic semiconductor production and technological self-reliance.

#### EUROPE

#### Sustainability and Regulation:

European nations are at the forefront of sustainable technologies, driven by stringent environmental regulations and ambitious climate targets.

Focus Areas: Green chemistry, renewable energy integration, and sustainable manufacturing dominate, along with investments in clean transportation and digital infrastructure.

#### **Collaborative Frameworks:** A

culture of cross-border collaboration (e.g., through the European Union's innovation programs) and public funding support enables scalable solutions that balance impact with economic returns.

Israel, for example, is renowned for its intense focus on cybersecurity, health tech, water tech, and Al-driven hardware solutions.

**Export Oriented:** As a result of a small local economy, start-ups are built for a global market on day one.

Investors should view these regional differences as complementary rather than contradictory. Each region offers unique strengths and faces distinct challenges. By balancing investments across these clusters, investors can not only capture superior returns but also contribute to a diversified, resilient global hard tech ecosystem.

#### **ISRAEL AND OTHER** SPECIALIZED HUBS

#### **Boutique Innovation Clusters:**

Start-Up Culture: With a culture of rapid innovation and a high density of tech talent, such clusters provide opportunities for breakthrough technologies that can be scaled globally.

#### ASIA PACIFIC

Manufacturing Powerhouse: East Asia, particularly Taiwan, South Korea, and China, remains central to high-end manufacturing and semiconductor fabrication. These clusters benefit from significant economies of scale and advanced production techniques.

Focus Areas: The region leads in hardware manufacturing, smart manufacturing, and resourceefficient production processes. Investment in clean tech and water recycling in semiconductor production is also prominent.

**Government Initiatives:** Robust state support—through subsidies, infrastructure investments, and industrial policies—drives rapid innovation, though geopolitical tensions and regulatory shifts must be closely monitored.

#### JAPAN

**Innovation Heritage:** Japan's longstanding excellence in fields ranging from semiconductor materials to life sciences underpins both its advanced manufacturing and fundamental science capabilities. Its focus on quality and continuous improvement (kaizen) distinguishes its industrial approach.

Focus Areas: The nation excels in next-generation automation, smart manufacturing, and sustainable energy, with significant investments in R&D that bridge traditional practices with emerging hard tech solutions.

#### **Government & Industry**

**Collaboration:** A stable regulatory environment and strong publicprivate partnerships foster innovation. Strategic government support and a culture of meticulous quality control enable Japan to maintain its competitive edge without the geopolitical volatility seen in other parts of Asia-Pacific.

#### **EMERGING MARKETS**

#### **New Innovation Clusters:**

Regions in Southeast Asia, India, and parts of Latin America are emerging as fertile ground for hard tech startups, particularly in agricultural tech, decentralized manufacturing, and renewable energy solutions.

#### **Localized Advantages:**

These markets offer unique opportunities to address local resource challenges and scale technologies that are both cost-effective and adaptable to diverse environments.

#### **Investment Considerations:**

While these regions may present higher risks due to political and economic volatility, they also offer substantial growth potential and a chance to drive inclusive innovation.

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Why Hard Tech

#### **Cross Cutting Themes**

#### **Deep Dives:**

Climate Innovation & Sustainable Systems

Computational & Physical Infrastructure

Human Health & Bioengineering

**Regional Differences in** Hard Tech Innovation

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## Japan: A Unique Blend of Tradition and Innovation

Japan remains a cornerstone of hard tech innovation, with a long history of innovation in fields ranging from semiconductor materials to life sciences leveraged by decades of manufacturing excellence. With a legacy of precision engineering and advanced robotics, the nation continues to push the envelope in fields such as automated manufacturing, advanced materials, and sustainable energy solutions.

Japanese companies such as Toyota, Sony, Hitachi, Shin-Etsu, muRata, Nitto Denko, and others hold global leadership positions across many different business sectors. These companies are not only renowned for their operational excellence but are also pioneering new technologies—from next-generation robotics and AIdriven production systems to eco-friendly manufacturing processes.

The country's commitment to continuous improvement, or kaizen, underpins its efforts to optimize efficiency while reducing environmental impact, ensuring that innovation is both transformative and sustainable.

Government initiatives and strategic investments in research and development further bolster Japan's hard tech ecosystem. Collaborations between industry giants, startups, and academic institutions are fostering a vibrant environment where traditional strengths are seamlessly integrated with digital technologies. This convergence is accelerating the development of smart factories, precision automation, and novel energy storage solutions that address both economic and societal challenges.

For investors, Japan offers a compelling blend of time-tested expertise and dynamic innovation, providing a unique opportunity to engage with a market that consistently delivers high-quality, impactful technological breakthroughs.

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### **Looking Ahead:** The Inevitable Rise of Hard Tech in 2025

In 2025, hard tech isn't just another investment option: it's where history-making innovation now lives. While software delivered outsized returns for decades, today's greatest challenges—climate, energy, food security, and human health—demand physical solutions that software alone cannot provide.

The convergence of computational breakthroughs, advanced materials science, and advanced manufacturing has collapsed development timelines from decades to years. What was once theoretical is now executable; what seemed impossible is now inevitable. This acceleration isn't merely a trend—it's a fundamental shift in how innovation materializes in our physical world.

At Pangaea Ventures, we recognize this moment as more than an opportunity, it's an inflection point where the integration of AI-enhanced discovery, novel materials, and bioengineering isn't just creating new industries but redefining our industrial foundation. From quantum-resistant semiconductors to regenerative medicine platforms, these innovations are establishing the infrastructure for a more resilient, sustainable future.

The global landscape only reinforces this inevitability. Geopolitical pressures, resource constraints, and climate imperatives are no longer abstract considerations but concrete market forces driving capital toward hard tech solutions. As international competition intensifies and supply chains reconfigure, nations and enterprises that master these physical technologies will determine the next century's winners.

Our conviction is unwavering: The next wave of trillion-dollar companies won't be built in bits, but in atoms. Hard tech in 2025 represents not just incremental improvement but transformative reinvention of our industrial capabilities. By investing in these physical innovations today, we're not simply anticipating the future—we're backing its inevitable arrival.

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## About This Report

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