

# Convergence of Next-Generation Technologies and the Evolution of Web3: The Roles of Blockchain and AI Redefined by Quantum Computing, Synthetic Biology, and the Metaverse

## 1. Background and Current Status: The Arrival of a Paradigm Shift in the Macro Environment

By 2026, the global technology landscape has firmly transitioned from tracking isolated advancements to a phase of "Convergence," where multiple deep-tech domains evolve in a deeply intertwined manner. Historically, the Web3 and cryptocurrency industries primarily focused on financial speculation and early experiments in digital ownership via Decentralized Finance (DeFi) and Non-Fungible Tokens (NFTs). Today, however, blockchain technology and Artificial Intelligence (AI) have assumed far broader and more fundamental roles: building defensive infrastructures against the exponential leap of quantum computing, democratizing data analysis and funding in synthetic biology, and automating highly interoperable economic systems within the metaverse.

The objective of this report is to provide a comprehensive overview of this "next-after-next" technological wave, dissecting the roles of blockchain and AI in conjunction with cutting-edge technologies from both strategic and investment perspectives. Specifically, this analysis delves into three critical areas: the vanguard of Post-Quantum Cryptography (PQC) defending against AI-accelerated quantum threats, the synthetic biology innovations spearheaded by AI agents and Decentralized Science (DeSci), and the tokenomics redefining economic structures in the virtual worlds of the metaverse. These technologies do not operate in silos; they are co-developing upon a shared foundation of AI's enhanced reasoning capabilities and blockchain's trustless value-transfer mechanisms. Through this analysis, we clarify the core principles, market applications, quantitative growth forecasts, and inherent risks of each technology to identify next-generation investment opportunities.

## 2. The Quantum Computing Threat and the Fundamental Redefinition of Web3 Security

### 2.1 AI Accelerates "Q-Day" and the Structural Vulnerabilities of Blockchains

For years, "Q-Day"—the theoretical date when quantum computers will be capable of breaking

existing public-key cryptography—was considered decades away. However, the fusion of AI and quantum computing has drastically compressed this timeline.<sup>1</sup> Machine learning systems are currently assisting researchers in discovering quantum-compatible materials and optimizing algorithms at unprecedented speeds, forming an "AI-Quantum Feedback Loop" that constantly accelerates hardware development.<sup>1</sup> Research published by Google's Quantum AI team in March 2026 demonstrated that Shor's algorithm has been highly optimized, proving that breaking elliptic curve cryptography (ECC) theoretically requires under 500,000 physical qubits, a number significantly lower than previous estimates.<sup>1</sup>

This reality presents an existential crisis for standard blockchain networks like Bitcoin and Ethereum. Traditional security models rely on mathematical problems (like prime factorization) that take classical computers millennia to solve.<sup>1</sup> However, a quantum machine running Shor's algorithm can process these factors exponentially faster.<sup>1</sup> Attackers do not need to break the underlying blockchain consensus protocol; they can simply target the individual wallet level, intercepting exposed public keys during transactions to derive private keys and drain funds.<sup>1</sup> Furthermore, the "Harvest Now, Decrypt Later" strategy is an active, ongoing emergency. Sophisticated state actors and cybercriminal networks are actively vacuuming up unencrypted internet traffic, transactional data, and unspent transaction output (UTXO) data from blockchains today.<sup>1</sup> The moment quantum supremacy is achieved, any intercepted legacy data unprotected by post-quantum cryptography becomes instantly exploitable.<sup>1</sup> Therefore, the migration to quantum-resistant encryption is not a future challenge, but a present necessity.

## 2.2 Post-Quantum Cryptography (PQC) Principles and NIST Standardization

To address this cryptographic crisis, the U.S. National Institute of Standards and Technology (NIST) finalized its first post-quantum cryptography standards in August 2024, culminating an eight-year effort involving top global cryptographers.<sup>2</sup> The selected algorithms rely on complex mathematical structures (such as lattice problems and hash functions) that remain highly difficult for both classical and quantum computers to solve efficiently.<sup>4</sup>

NIST Standard	Algorithm Name	Cryptography Type	Main Use Case
FIPS 203	ML-KEM	Lattice-based	Key encapsulation (Key exchange) <sup>4</sup>
FIPS 204	ML-DSA (Dilithium)	Lattice-based	Digital signatures <sup>4</sup>
FIPS 205	SLH-DSA	Hash-based	Digital signatures <sup>4</sup>

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In addition to standardization, NIST's National Cybersecurity Center of Excellence (NCCoE) is leading a project to facilitate the migration by testing interoperability and supporting technology vendors in implementing PQC.<sup>3</sup> Because NIST standards carry significant regulatory weight, particularly in the U.S., financial institutions and compliance-heavy infrastructures are rapidly shifting to these solutions.<sup>5</sup> The rigorous nature of this transition is underscored by the fact that out of 40 initial digital signature candidates, only 14 survived to the second round, and 9 to the third, highlighting the critical importance of "crypto-agility"—the ability to update cryptographic systems as vulnerabilities are discovered.<sup>6</sup>

### 2.3 PQC Implementation in Blockchain Protocols and Technical Tradeoffs

The Web3 industry is responding with diverse approaches, sparking intense competition between legacy networks undergoing complex upgrades and new networks natively built with PQC architectures.

Ethereum has established a dedicated post-quantum research team and set out a "Lean Ethereum" roadmap targeting full post-quantum protection by 2029.<sup>4</sup> This involves migrating structures like Abelian groups used in Zero-Knowledge (ZK) proof systems, which are vulnerable to Shor's algorithm.<sup>4</sup> However, since quantum resistance must be balanced against a backlog of other scalability upgrades, this transition is a long-term endeavor.<sup>5</sup>

Conversely, newer projects are deploying PQC natively. Circle, the issuer of USDC, is developing "Arc," a Layer-1 blockchain that integrates NIST-standard lattice-based algorithms (ML-DSA, CRYSTALS-Dilithium, and Falcon) from genesis.<sup>5</sup> With a mainnet targeted for 2026, Arc will support post-quantum signatures from its very first block.<sup>5</sup> Similarly, Algorand achieved a major milestone in November 2025 by executing its first mainnet Falcon-1024 transaction, proving that quantum-level security can coexist with high throughput speeds of 10,000 TPS.<sup>7</sup>

Several networks designed from the ground up for quantum resistance are also maturing. The Quantum Resistant Ledger (QRL), active since 2018, utilizes the NIST-validated XMSS hash-based signature scheme and has maintained a flawless security record for seven years.<sup>7</sup> QRL's "Project Zond" is currently introducing EVM compatibility and the SPHINCS+ algorithm.<sup>7</sup> Other notable architectures include IOTA's DAG structure with hash-based signatures, Abelian's privacy-focused lattice cryptography, and Cellframe's modular design that allows for seamless PQC standard updates without hard forks.<sup>7</sup>

Project	Key Algorithm / Approach	Current Status & Features
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Ethereum	To be determined	Targeted for 2029 (Lean Ethereum Roadmap) <sup>4</sup>
Circle Arc	ML-DSA, Dilithium, Falcon	Mainnet in 2026; USDC as native gas token <sup>5</sup>
Algorand (ALGO)	Falcon-1024	Mainnet live (Nov 2025); high throughput <sup>7</sup>
QRL	XMSS, SPHINCS+	Operating since 2018; EVM compatibility upcoming <sup>7</sup>
Cellframe (CELL)	Lattice/Modular	PQC-native; modular design avoids hard forks <sup>7</sup>
QANplatform (QANX)	CRYSTALS-Dilithium	PoS Layer 1; EVM compatible for standard languages <sup>7</sup>
IOTA (IOTA)	Hash-based (DAG)	PQC-native; designed for IoT/M2M scalability <sup>7</sup>
Abelian (ABEL)	Lattice-based	PQC-native; focuses heavily on privacy <sup>7</sup>

Despite this progress, PQC implementation introduces severe technical tradeoffs. The primary challenge is that post-quantum signatures are significantly larger than classical signatures, which can bloat block sizes, throttle transaction throughput, and dramatically increase storage costs for node operators.<sup>5</sup> Furthermore, innovative solutions like the "QFlex" cryptographic logistics layer by BOLTS are emerging, allowing asset holders to adjust security levels on a per-transaction basis (using lightweight crypto for small transfers and heavy PQC for institutional settlements) without requiring underlying protocol changes.<sup>6</sup>

## 2.4 Fusing Quantum Communication (QKD) and Blockchain for Information-Theoretic Security

Parallel to algorithmic upgrades (PQC), the physical layer of Web3 infrastructure is being secured via Quantum Key Distribution (QKD). Based on protocols like BB84 proposed in 1984, QKD securely exchanges encryption keys using the quantum states of photons.<sup>8</sup> Any attempt to eavesdrop disturbs the quantum state, alerting the parties and effectively rendering interception physically impossible.<sup>9</sup>

Integrating QKD into decentralized consensus mechanisms eliminates single points of failure

and key escrow vulnerabilities, achieving "information-theoretic security".<sup>10</sup> Combined with hybrid PQC signatures, this synergy eradicates the threat of Man-in-the-Middle and Sybil attacks.<sup>10</sup> While transmission distance and specialized hardware requirements remain hurdles, long-distance QKD over fiber-optic cables and free-space links is rapidly advancing.<sup>9</sup> Projects like the European Quantum Communication Infrastructure (EuroQCI) aim to build a secure backbone across the EU by 2027.<sup>8</sup> In the private sector, the Hedera network has partnered with semiconductor firm SEALSQ to embed Dilithium keys into FIPS-compliant, quantum-resistant secure chips directly at the node level.<sup>8</sup>

## **3. Decentralized Science (DeSci) and the AI-Powered Renaissance in Synthetic Biology**

### **3.1 Eroom's Law and the Bottlenecks of Traditional Science**

Despite technological advancements, modern scientific research suffers from severe productivity stagnation. Known as "Eroom's Law" (the reverse of Moore's Law), the number of new drugs approved per billion US dollars of R&D investment has halved approximately every 9 years since 1950.<sup>11</sup>

This slowdown is heavily attributed to centralized academic institutions and for-profit publishing systems. Researchers lose immense time to grant applications and unpaid peer reviews, while commercial publishers hoard the profits.<sup>11</sup> Furthermore, publication bias ensures that only successful experiments are shared, leaving valuable failed data siloed.<sup>12</sup> Crucially, the intellectual property (IP) generated often belongs to opaque institutions rather than the researchers, perpetuating a system characterized by "inventor poverty".<sup>12</sup>

### **3.2 The Rise of DeSci and the Liquidation of Data via IP-NFTs**

Decentralized Science (DeSci) seeks to dismantle these structural flaws using blockchain technology to emphasize transparency, rapid funding, and open-source principles.<sup>11</sup>

Infrastructure providers like DeSci Labs utilize FAIR data standards to store manuscripts, code, and datasets on decentralized networks (like Arweave and Filecoin), ensuring permanent, tamper-proof access.<sup>14</sup>

The paramount paradigm shift in the DeSci ecosystem is the invention of the "IP-NFT," which tokenizes intellectual property into programmable smart contracts on the blockchain.<sup>13</sup> The Molecule platform pioneered this model, migrating biotech IP away from closed patent systems and allowing investors to purchase equity in specific research segments.<sup>13</sup> This approach has proven to shorten early-stage financing cycles by up to 60%.<sup>13</sup>

This decentralized framework is already achieving mainstream pharmaceutical adoption.

Giants like Pfizer and Bayer have formally partnered with Molecule.<sup>16</sup> Pfizer utilized the platform to transform early drug discovery into IP-NFTs, successfully optimizing R&D costs by 40% while implementing a smart contract that automatically routes a 15% continuous royalty

share back to the original scientific contributors—effectively resolving inventor poverty.<sup>13</sup> Molecule has facilitated over \$200 million in research funding flows, establishing itself as the premier translational marketplace for biotech.<sup>16</sup>

### 3.3 Bio Protocol and the Emergence of Autonomous BioAgents

As scientific data moves on-chain, AI is driving an "agentic science" revolution by automating the research pipeline itself. Central to this is the **Bio Protocol**, a decentralized financial layer for biotechnology that integrates scientific AI with blockchain economics.<sup>17</sup>

Bio Protocol operates via a network of specialized Biotech DAOs (BioDAOs) like VitaDAO (longevity), AthenaDAO (women's health), and Cerebrum DAO (brain health).<sup>17</sup> Community members use the native \$BIO token to curate and fund projects via "Ignition Sales".<sup>19</sup>

With the launch of Bio Protocol V2 in Q3 2025, the ecosystem deployed its most significant breakthrough: Scientific AI Agents (BioAgents).<sup>17</sup> These agents autonomously manage research through the following mechanisms:

1. **BIOS (The AI Scientist):** A general-purpose AI engine that conducts deep literature synthesis, novelty detection, and rapid hypothesis generation on a pay-per-query basis.<sup>20</sup>
2. **Economic Autonomy (x402 Rails):** BioAgents possess autonomous wallets integrated with the x402 payment rail. They receive budget allocations and autonomously pay USDC to other agents or APIs for cognitive resources and data.<sup>17</sup>
3. **Cloud Lab Integration:** Agents bridge the gap between computational and physical science by connecting directly to real-world cloud "wet labs." An agent can generate a protocol, pay for the physical experiment from its wallet, and have the resulting data fed directly back into its encrypted memory for continuous learning.<sup>19</sup>

The power of this system was validated by "Aubrai," the first BioAgent launched in August 2025 in collaboration with VitaDAO and longevity researcher Dr. Aubrey de Grey.<sup>19</sup> Trained on Dr. de Grey's data, Aubrai generated over 1,000 scientific hypotheses on-chain in its first few weeks, autonomously secured \$900,000 in research funding, and saw its native token (\$AUBRAI) valuation skyrocket 150x from \$269,000 to \$40 million.<sup>19</sup>

### 3.4 Synthetic Biology and Climate Applications: The ValleyDAO Case

The fusion of DeSci and AI-driven synthetic biology extends beyond pharmaceuticals into climate change mitigation and sustainable materials. **ValleyDAO** leads this sector, funding industrial biotechnology and synthetic biology projects aimed at environmental restoration.<sup>21</sup>

ValleyDAO utilizes "Tech Trees"—structured knowledge bases mapped by Large Language Models (LLMs) to define problems, aggregate data, and highlight pathways to overcome scientific obstacles.<sup>23</sup> Researchers are incentivized with token-based rewards (\$GROW) to contribute to and curate these trees.<sup>21</sup>

A prime success story is the **Tattva** project, which developed "Stromate"—a carbon-negative

biomaterial utilizing engineered cyanobacteria to sequester CO<sub>2</sub> while maintaining the strength and fire resistance of conventional construction materials.<sup>24</sup> Through ValleyDAO, the project secured vital funding in under two months and transitioned into generating industry partnerships via its IP token.<sup>21</sup> Furthermore, ValleyDAO's AI platform, "Phlo," empowers researchers to de-risk technology, conduct rapid literature reviews, and construct business models, dramatically accelerating the journey from lab bench to scalable solutions.<sup>24</sup>

## **4. The Maturation of the Metaverse Economy and Advanced Tokenomics**

### **4.1 Shifting from Hype to Utility**

While the metaverse experienced a period of inflated expectations followed by stagnation in the early 2020s, industry analysts define 2026–2030 as the "Commercial Adoption Era".<sup>25</sup> The market has successfully transitioned from mere potential to actual commercial performance and utility.<sup>26</sup>

This inflection point is heavily driven by hardware accessibility, with VR headsets dropping below the \$300 mark and approaching 200 million annual shipments.<sup>26</sup> Consequently, global daily active users (DAUs) across metaverse platforms have surpassed 50 million.<sup>26</sup> The metaverse is no longer just for gaming; it functions as a robust digital economy hosting avatar-driven retail showrooms, corporate training simulations, and immersive 3D workspaces for decentralized autonomous organizations (DAOs).<sup>26</sup>

### **4.2 Metaverse Tokenomics and True Interoperability**

In the metaverse, blockchain's primary function is enforcing "verifiable and persistent property rights" for digital assets.<sup>27</sup> Metaverse tokenomics governs how users acquire, utilize, and retain virtual land, digital wearables, and identities.<sup>27</sup> Because these assets are treated as genuine property, any economic policy shift (like royalty structures or token sinks) is immediately priced in as policy risk by investors.<sup>27</sup>

The hallmark of the 2026 metaverse economy is cross-platform interoperability. Standardized digital identities and asset protocols allow users to fluidly transport their avatars and NFT wearables between previously siloed environments (e.g., from The Sandbox to Decentraland), which exponentially deepens market liquidity and transactional frequency.<sup>25</sup>

### **4.3 AI and the Rise of Infrastructure Tokens**

Artificial Intelligence serves as the automated workforce sustaining this complex digital economy. AI-driven avatars act as customer service representatives in virtual storefronts, while procedural AI tools instantly generate personalized 3D environments and video content on demand.<sup>26</sup>

To support this massive computational and transactional load, investment capital has shifted

heavily toward the "infrastructure tokens" that provide the metaverse's structural backbone.<sup>26</sup>

Token	Role in Metaverse Economy & Tech Edge	Tokenomics & Adoption
Render (RNDR)	Connects idle GPUs for 3D/AI rendering; migrated to Solana for 90% cost reduction <sup>26</sup>	Rewards GPU providers; high demand from Hollywood studios <sup>26</sup>
Immutable (IMX)	Layer-2 scaling solution enabling gasless NFT minting with up to 9,000 TPS <sup>26</sup>	Foundational infrastructure for gaming and metaverse microtransactions <sup>26</sup>
Enjin Coin (ENJ)	Powers interoperable NFTs across 200+ games utilizing Efinity and JumpNet <sup>26</sup>	Standardizes asset liquidity across virtual worlds <sup>26</sup>

#### 4.4 Developments in Key Metaverse Worlds and Gaming Projects

Platforms built atop these infrastructures are exhibiting strong utility-driven growth:

- **The Sandbox (SAND):** Driving the creator economy with voxel-based content and AI design tools, recently recording over \$10 million in virtual land sales in a single month.<sup>26</sup>
- **Axie Infinity (AXS):** Having completely recovered from a devastating \$625 million hack in 2022, the ecosystem stabilized its Ronin network and rebounded to over 500,000 DAUs in early 2026.<sup>26</sup>
- **ApeCoin (APE):** Governing the Otherside metaverse, it manages a \$1 billion treasury and maintains massive brand appeal, having generated \$560 million during highly anticipated land mints.<sup>26</sup>
- **Alien Worlds (TLM):** Operating across multiple chains, it maintains over 1.2 million daily active on-chain players through its complex political economy governed by planetary DAOs.<sup>28</sup>

These ecosystems are converging into a "hybrid commerce model"—combining intuitive, centralized user experiences with decentralized custody and settlements.<sup>25</sup> Sophisticated monetization strategies, such as rent-to-own assets, subscriptions, and automated secondary-sale royalties, are natively enforced via smart contracts.<sup>25</sup>

## 5. Comprehensive Investment Analysis: Market Size,

# Competition, and Risk Assessment

When strategizing for "next-after-next" technology investments, it is crucial to recognize that quantum computing, synthetic biology, and the metaverse are not disparate sectors; they are deeply interconnected via blockchain trust layers and AI reasoning engines. This section details the quantitative market metrics and the associated regulatory and technical risks critical for investment evaluation.

## 5.1 Quantitative Analysis of Market Size and CAGR

Market data indicates explosive, sustained growth across these intersecting sectors over the coming decade.

Area / Sector	Market Size (2024-2026)	Long-Term Forecast	CAGR	Key Drivers
Quantum Crypto (PQC)	~\$1.2B (2024) <sup>29</sup>	~\$10.2B (2031) <sup>29</sup>	35.7% - 39.5% <sup>30</sup>	Financial/defense infrastructure migration due to Q-Day; NIST mandates <sup>3</sup>
Decentralized Science (DeSci)	~\$1.0B (2026) <sup>13</sup>	>\$50.0B (2030) <sup>13</sup>	35.0% <sup>13</sup>	AI agent automation; IP-NFT capital liquidity <sup>13</sup>
Synthetic Biology	~\$23.5B (2026) <sup>31</sup>	\$56.4B - \$112.5B (2031-2033) <sup>32</sup>	11.5% - 22.7% <sup>33</sup>	CRISPR therapies; AI-driven climate/biomaterial solutions <sup>32</sup>
Digital Biology	N/A	+\$29.8B net growth by 2030 <sup>34</sup>	20.1% <sup>34</sup>	AI/ML integration into genomic sequencing and in-silico simulations <sup>34</sup>

Metaverse Economy	~\$400B (2026) <sup>26</sup>	~\$1.3T (2032) <sup>25</sup>	46.4% <sup>25</sup>	Sub-\$300 VR headsets; AI automated commerce; interoperable infrastructure <sup>26</sup>
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## 5.2 Regulatory Risks and Compliance Trends

Regulatory uncertainty remains a prominent risk factor at the intersection of these technologies.

First, regarding metaverse virtual economies, governments are accelerating compliance frameworks. Following the UAE and Singapore, the U.S. is advancing the "Clarity Act" to define digital asset market structures and the "Genius Act" for stablecoin regulation.<sup>35</sup> While clarity invites institutional capital, emerging policies like digital services taxes and strict cross-border asset transfer laws may significantly inflate compliance costs.<sup>25</sup>

Second, the DeSci sector faces a collision between data privacy laws and blockchain immutability. Managing personalized genomic or synthetic biology data on-chain creates intense friction with mandates like the GDPR's "right to be forgotten," as data recorded on a decentralized ledger cannot be easily erased.<sup>36</sup> Furthermore, as autonomous BioAgents commission physical lab experiments and generate novel drug protocols, determining legal liability and navigating FDA approval pathways for AI-generated compounds remain uncharted regulatory territories.

## 5.3 Technical Risks and Market Fragmentation

The most immediate technical risk lies in the scalability tradeoffs inherent in Post-Quantum Cryptography (PQC). Because NIST-approved algorithms like Dilithium and Falcon require much larger signature sizes, they risk inducing state bloat, choking transaction throughput, and inflating node operating costs.<sup>5</sup> The long-term dominance of PQC-native chains like Arc and Algorand will largely depend on their ability to mitigate this bloat in high-demand environments.<sup>5</sup>

Additionally, market fragmentation poses a threat to both DeSci and the Metaverse. Without unified interoperability standards, fractured digital identities and isolated IP-NFT ecosystems will suppress economic liquidity. Investors must heavily scrutinize projects, favoring foundational infrastructure layers and interoperability protocols over isolated, platform-specific applications.

# 6. Summary and Recommendations: Action Plan for the Next Paradigm

The frontier technologies of quantum computing, synthetic biology, and the metaverse are no longer evolving in isolation. By 2026, they have fundamentally converged, bound together by the computational engine of AI and the decentralized truth layer of blockchain.

While AI hastens the arrival of quantum threats to existing digital assets, the blockchain industry is actively defending itself via NIST-standardized PQC and quantum communication networks. Simultaneously, AI operates as an autonomous workforce (BioAgents) upon DeSci rails, synthesizing literature, ordering physical experiments, and democratizing funding via IP-NFTs—drastically accelerating synthetic biology. The metaverse serves as the ultimate interface where these digital ownership models, AI commerce, and decentralized GPU rendering seamlessly collide to form a trillion-dollar economy.

For stakeholders looking to capitalize on this next-generation technological wave, we propose the following strategic actions:

**1. Mandate "Crypto-Agility" in All Due Diligence:**

Evaluate Web3 investments strictly on their quantum threat mitigation roadmaps. Given the active "Harvest Now, Decrypt Later" threat, networks that lack a clear path to PQC integration (or modular upgradeability) will suffer severe risk discounts. The security of long-duration assets—such as virtual real estate and synthetic biology IP—depends entirely on this cryptographic transition.

**2. Reallocate Capital from the Front-End to Backend Infrastructure:**

Avoid overexposure to transient consumer hype in metaverse games or isolated DeSci research. Instead, deploy capital into the essential structural tokens that power the ecosystem. Assets that facilitate AI rendering (Render), provide gasless interoperability (Immutable, Enjin), or manage decentralized data liquidity offer vastly superior risk-adjusted returns due to their foundational utility.

**3. Capture Early Value in the "Agent Economy" via DeSci IP-NFTs:**

The capacity for AI agents to autonomously generate hypotheses, fund wet-lab experiments, and tokenize the resulting IP is poised to disrupt the legacy pharmaceutical and materials industries. Investors should actively participate in micro-funding mechanisms like Ignition Sales and acquire segmented IP-NFTs, positioning themselves early as stakeholders in meta-governance tokens (such as BIO and GROW) that dictate the future of automated scientific discovery.

The next Web3 paradigm is not merely populated by human users, but by autonomous AI economic agents, quantum-resistant validation nodes, and a global, decentralized scientific community. Understanding this macro-convergence and actively participating in its foundational infrastructure is the key to securing a decisive competitive advantage in the digital economy of the next decade.

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