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INNOVATION THEMES & STRATEGY

December 11, 2024

The Future Of Nuclear Energy And AI

In This Report

Following last week's *Innovation Themes & Strategy Fireside Chat*, we received an influx of questions that we believe are worth addressing in more detail. Clients were particularly interested in two key themes: (1) the future of nuclear energy and (2) the evolution of AI, with a focus on its decentralization.

This report utilizes clients' questions to explore these two themes in depth. The key takeaways are: (1) The uranium bull market is still in its early stages, with the next generation of reactors poised to significantly increase demand, and (2) AI is shifting from centralized to decentralized, through a move away from large, general-purpose models towards smaller, more specialized applications.

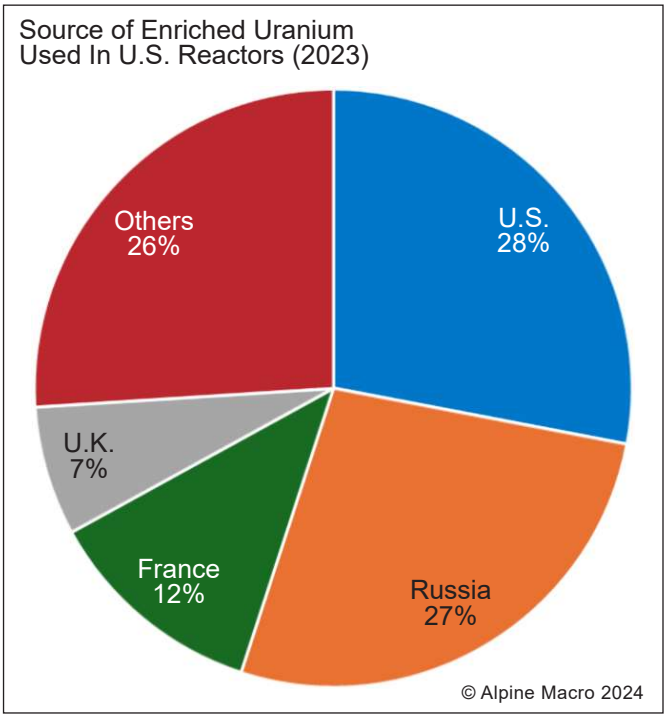
Uranium With A Focus On Next-Generation Nuclear

In 2024, we published two reports on uranium[1] that provide a comprehensive analysis of the structural supply deficit and key demand drivers. The following will unpack new developments and small modular reactors (SMRs).

• Geopolitical Impacts

Russia banned enriched uranium exports to the U.S. in November 2024. Last year, 27% of uranium used by U.S. reactors – enough to fuel 20 large reactors – was Russian enriched (Chart 1). This ban, largely symbolic, retaliates against the U.S.' self-imposed import ban, set to take full effect by 2028. Both restrictions complicate uranium procurement for U.S.

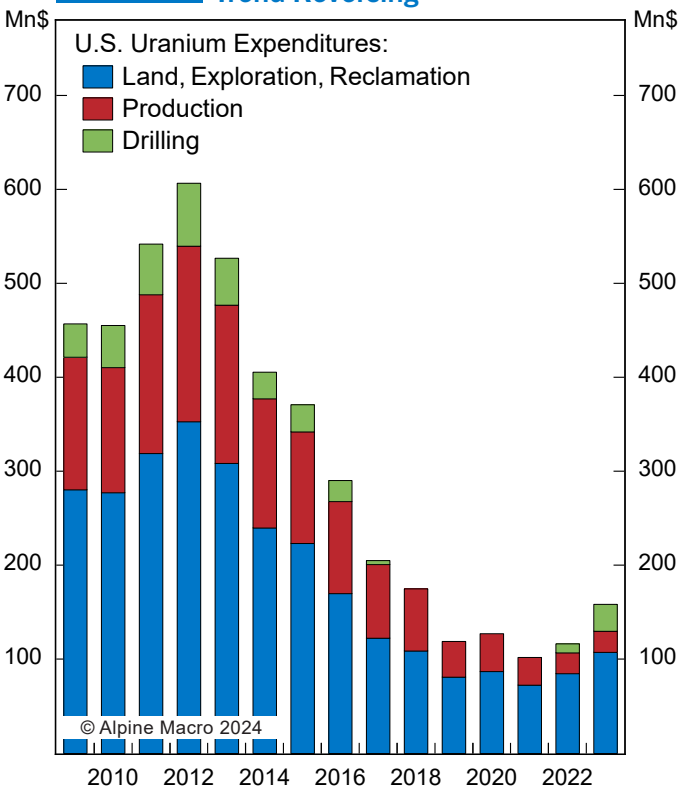
Chart 1 Largest Share Of U.S. Enriched Uranium Is Russian



Source: EIA

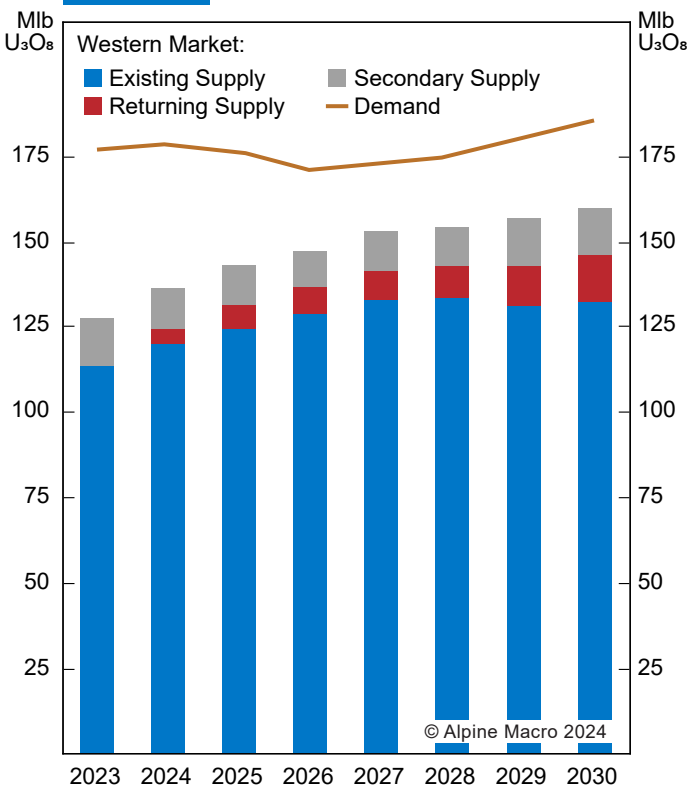
1 Alpine Macro *Innovation Themes & Strategy* "Uranium: A Nuclear Revival?" (July 1, 2024) and "Uranium: Another Leg Up?" (October 9, 2024).

Chart 2 Declining Investment Trend Reversing



Note: Drilling, land, exploration and reclamation data withheld for 2018-20 by EIA to avoid disclosure of individual company data; source: EIA

Chart 3 Structural Supply Deficit



Note: Demand includes reactor requirements and secondary demand; supply does not include new mine developments; Western market excludes Russia
Source: TradeTech, Uranium Market Study 2024: Issue 1

utilities and are likely to cause upward pressure on prices. Additionally, any conflict resolution in Ukraine is unlikely to affect the nuclear fuel cycle, as the U.S. and Western nations remain committed to nuclear independence. This is demonstrated by a reversing negative investment trend (**Chart 2**).

- **Uranium Price And Chances Of A Supply Shock**

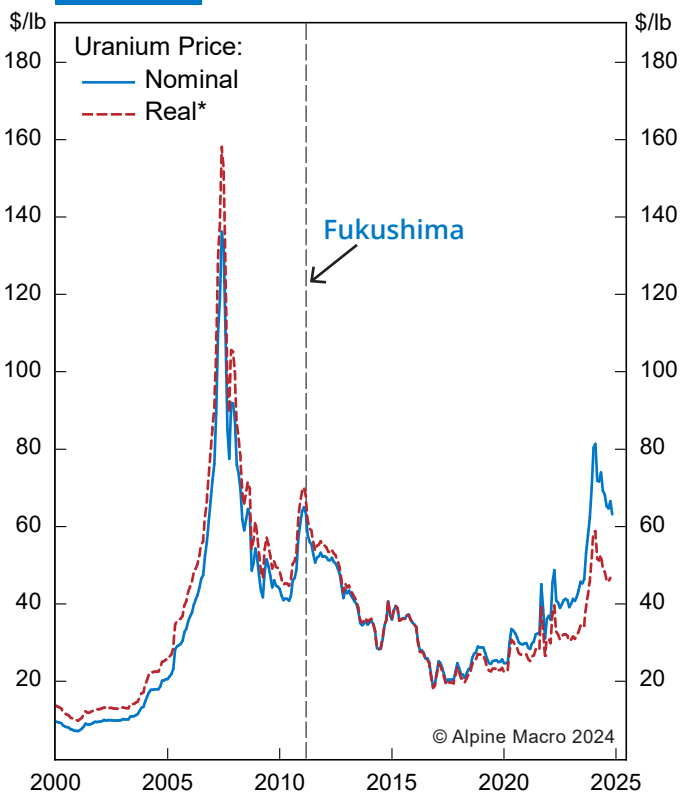
The current supply deficit is structural in nature (**Chart 3**). This stems from post-Fukushima low uranium prices, which discouraged exploration and rendered over 75% of mining unprofitable. Exploration budgets fell to record lows, no new mines were developed, and mining output was reduced at key assets.

Uranium prices surpassed $75/lb in November 2023 for the first time since 2008, a critical threshold for incentivizing new mining capacity (**Chart 4**). However, over 80% of uranium transactions occur in the long-term contract market, where prices now exceed $80/lb (**Chart 5**). While prices above $75/lb expand margins for miners and incentivizes development, key challenges remain giving us conviction that a sudden ramp-up in supply remains unlikely.

1. **Long Timelines:** Developing new mines takes 10-15 years depending on jurisdiction.

2. **Challenges With Current Output:** Downward tier* revisions at key trier 1 operating mines highlight challenges with increasing production.

Chart 4 Spot Price Rebound



*Deflated by OECD CPI
Source: IMF

3. **Delays:** Flagship mines under construction are behind schedule.

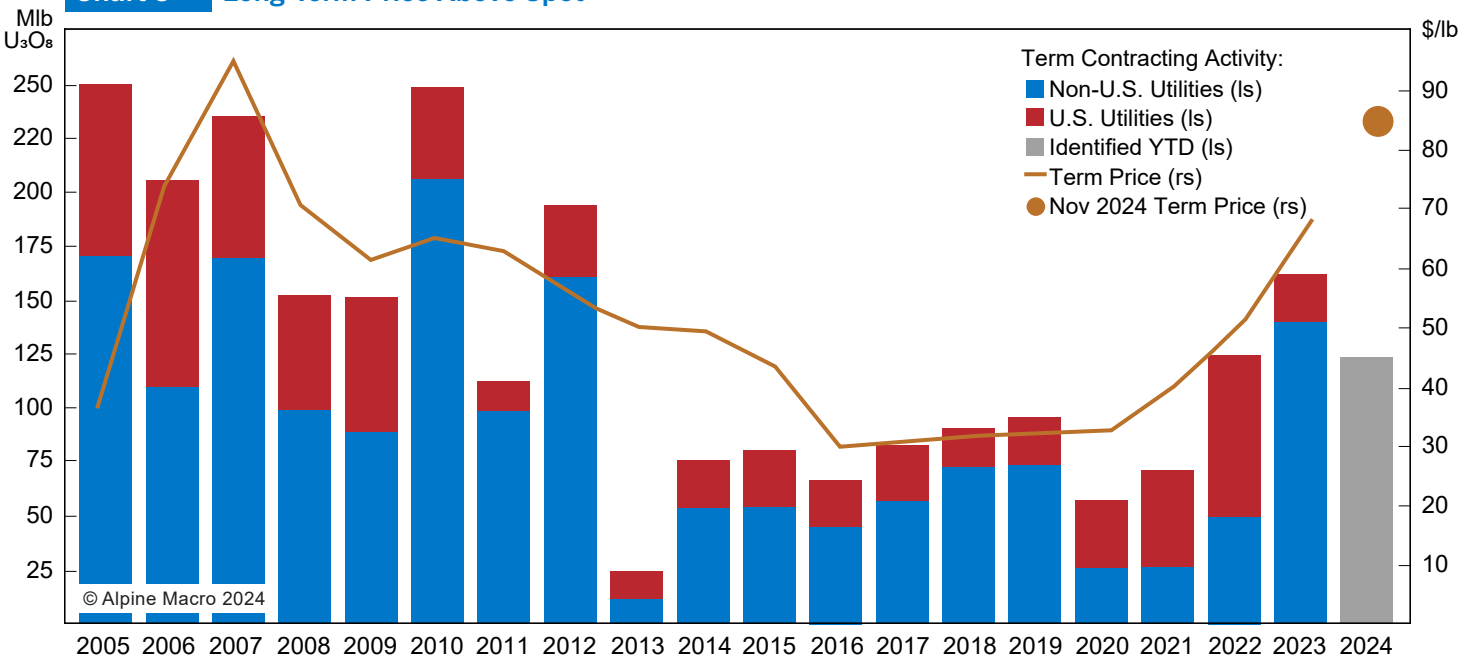
- **Next-Generation Nuclear**

SMRs represent a pivotal innovation for nuclear energy, improving efficiency, safety, and scalability. SMRs are nuclear energy's vessels to transition the energy form away from a history of accidents that have overshadowed benefits. There are over 80 designs in development worldwide (**Table 1** & **Chart 6**).

Key benefits include:

1. **Compact Design:** Smaller land footprint and modular construction.
2. **Passive Safety Features:** Reduced emergency planning zones due to inherent safety mechanisms.

Chart 5 Long-Term Price Above Spot



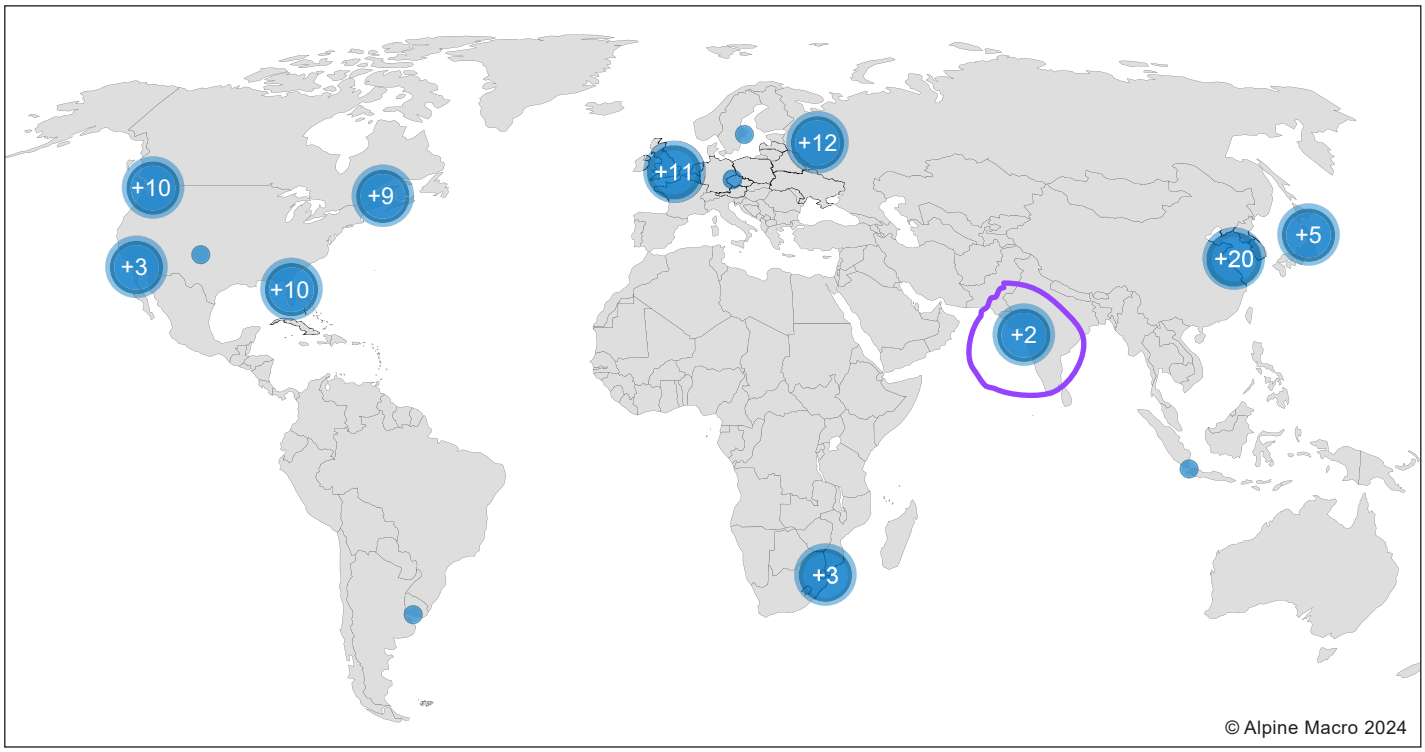
Source: UxC Uranium Market Outlook, Q1 2024

Table 1 Global SMR Innovation And Development

Name	Capacity (MWe)	Type	Developer
CNP-300	300	PWR	SNERDI/CNNC, Pakistan & China
PHWR-220	220	PHWR	NPCIL, India
EGP-6	11	LWGR	At Bilibino, Siberia (cogen, soon to retire)
KLT-40S	35	PWR	OKBM, Russia
RITM-200	50	Integral PWR, civil marine	OKBM, Russia
Designs Under Construction			
CAREM25	27	Integral PWR	CEA & INVAP, Argentina
HTR-PM	210	Twin HTR	INET, CNEC & Huaneng, China
ACP100/Linglong One	125	Integral PWR	CNNC, China
BREST	300	Lead FNR	RDIPE, Russia
Near-Term Deployment – Development Well Advanced (An excerpt)			
VBER-300	300	PWR	OKBM, Russia
NuScale Power Module	77	Integral PWR	NuScale Power + Fluor, USA
SMR-160	160	PWR	Holtec, USA + SNC-Lavalin, Canada
CNSP (Combined Nuclear/ Solar Plant)	300	PWR/HI-THERM HSP solar thermal system	Holtec, USA
SMART	100	Integral PWR	KAERI, South Korea
BWRX-300	300	BWR	GE Hitachi, USA
PRISM	311	Sodium FNR	GE Hitachi, USA
Natrium	345	Sodium FNR	TerraPower + GE Hitachi, USA

Source: World Nuclear Association

Chart 6 SMR Designs In Development



Source: World Nuclear Association

Molten-salt SMRs, which mix nuclear fuel with molten salt, stand above the rest in our view for three reasons:

1. **Energy Efficiency:** They operate at atmospheric pressure with a coolant boiling point of 1,400°C, eliminating the need for high-pressure systems and heavy materials like steel and concrete. Currently, most reactors are reliant on operating under internal pressure of over 2,000 psi to prevent water from boiling at core temperatures of 600°C.

2. **Operational Safety:** If molten salt escapes the reactor, it solidifies at ambient temperature, preventing contamination. Although this is highly unlikely, molten-salts' self cooling ability without human intervention adds an additional safety layer.

3. **Waste And RM Reduction:** SMRs require roughly 80% less energy to construct and 90% less steel and cement per kWh than traditional reactors. They also use High-Assay Low-Enriched Uranium (HALEU), a highly energy dense fuel that reduces nuclear waste by up to 90%.

- **Regulatory And Market Developments**

Although regulatory hurdles remain, interest in SMRs is surging, especially among data centers due to surging energy demand. The NRC recently approved construction permits for Kairos Power's Hermes 2 molten-salt reactors, marking the first Generation IV reactors approved in the U.S. for construction.

We note the Federal Energy Regulatory Commission's decision blocking the Amazon-Talen

Energy deal (planned to connect a 1,200-acre data center campus in Pennsylvania to the adjacent Susquehanna nuclear plant) reflects broader concerns about infrastructure costs for larger reactors and the transfer of cost onto energy consumers, not issues specific to SMRs or AI-related energy demand. Regulatory hurdles for SMRs could be reduced under Trump, with Trump-elected leadership at the NRC poised to accelerate approvals.

A Shift To Specialized AI And The Coming Rise Of "Decentralized AI"

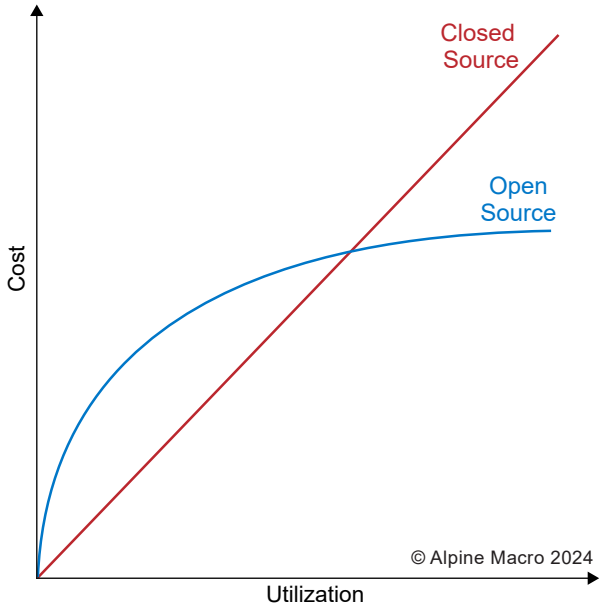
AI is shifting from centralized control by big tech to a decentralized future, driven by small, specialized open-source models tailored for niche applications.

- **Niche AI Vs All-Encompassing Models**

The notion that "bigger is better" in AI is being challenged. While large models like GPT-4 with 1.8 trillion parameters are versatile across general utilization, smaller models with 10-100 million parameters excel in specific tasks due to their efficiency and speed. We are in the camp that AI's most impactful and productivity improving use cases will be a result of the rise of small language models (SLMs) built on the back of large language models (LLMs).

Taking things one step further, AI's most profound shift in the short term will be its evolution into open-source, models. These models embody a step change for the pursuit of an "all-encompassing" AI, to one that prioritizes specialization over scale (**Chart 7**). Already, enterprise leaders are embracing open-source models with them targeting a 50/50 split in utilization (**chart 8**).

Chart 7 Open Source Reduces Cost And Improves Utilization



Source: Sergei Savvov "You don't need hosted LLMs, do you?"

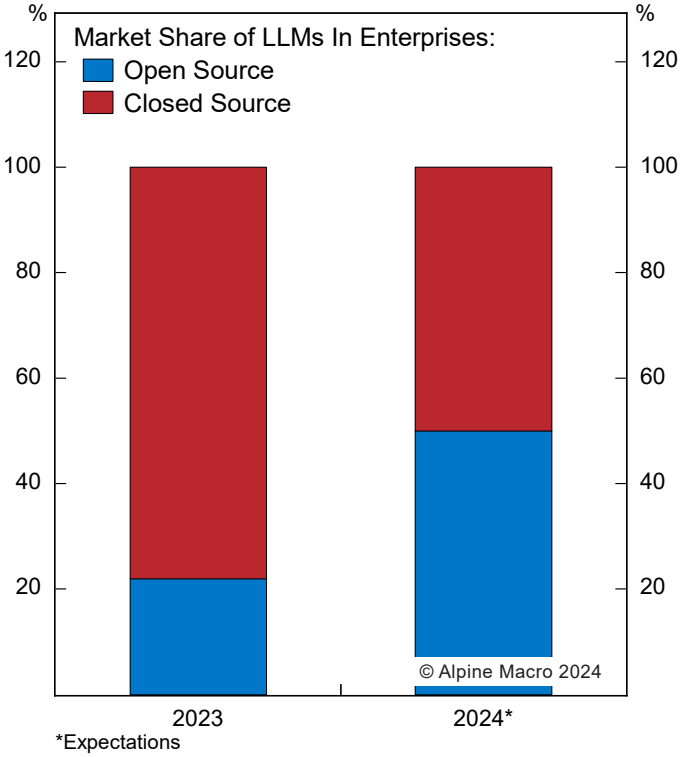
Open-source platforms like Hugging Face, which hosts over 700,000 models, are making specialized AI more accessible. This is being built upon decentralized technology.

- **AI And Blockchain Symbiosis: Decentralized AI (DAI) Emerges**

Despite their differences in size and ownership, both big tech's LLMs and open-source SLMs face common challenges such as bias, transparency, and accuracy. Addressing these issues is crucial for creating unbiased, transparent, and reliable AI. The solution is Decentralized AI (DAI), which leverages blockchain technology to build, train, and run LLMs, democratizing AI across both creation and consumption.

The convergence of blockchain and AI is gaining momentum with growing research and development efforts. Patents and research publications related to blockchain+AI have seen

Chart 8 Open Versus Closed Blended Adoption



*Expectations
Source: Andreessen Horowitz

a significant increase (Chart 9). Last year, the value of 15 AI-related tokens surged by 443% to $12 billion, outpacing the overall crypto market's 108% growth.

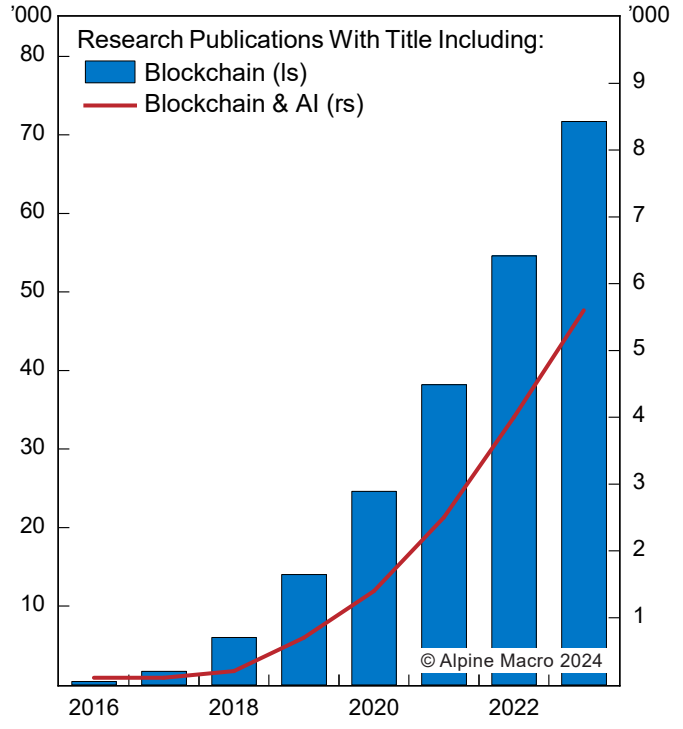
- **DAI Operates On A "Stacked" Architecture, Comprising Three Layers (Chart 10):**

1. **Application Layer:** Focuses on user interfaces and business logic, enabling interaction through tools, apps, or dashboards.

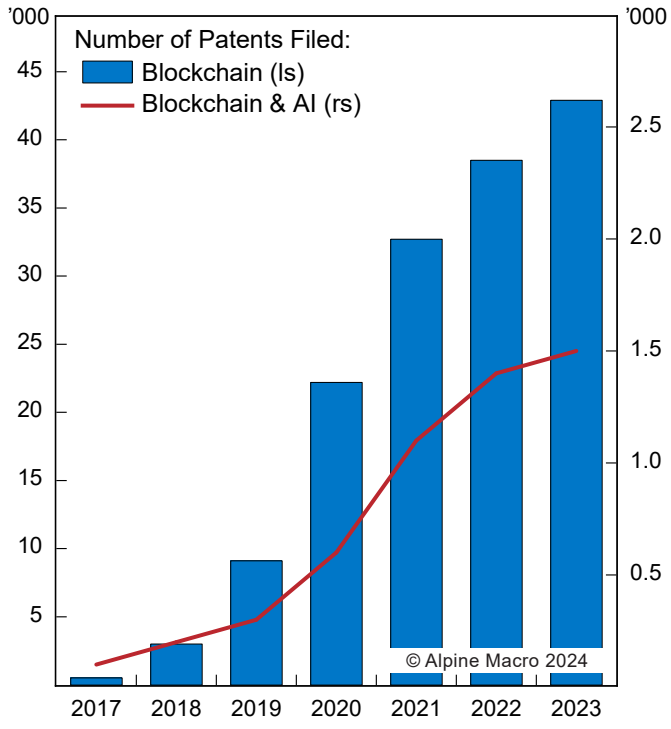
2. **Middleware Layer:** Connects the application to the infrastructure, managing data flow, APIs, and communication between systems.

3. **Infrastructure Layer:** Provides computational resources, storage, and networking for the middleware and application layers.

Chart 9 Growing Attention To Blockchain+AI

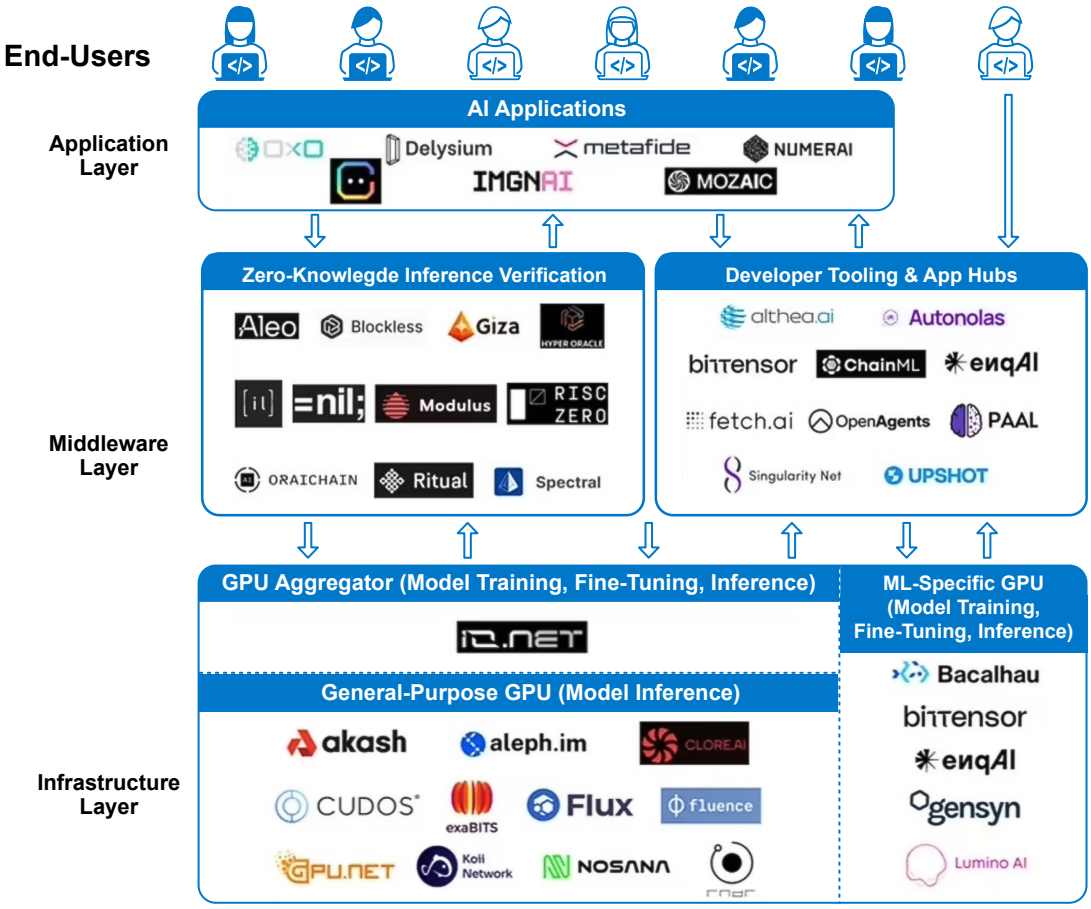


Source: Dimensions.ai



Source: World Intellectual Property Organization

Chart 10 Level Of DAI



Source: David Atterman

- **A DAI Future**

DAI is poised to make AI development more efficient and affordable. Through blockchain, GPU owners can "sublet" unused computing power to the DAI network for model training. Additionally, decentralized data storage is much cheaper than traditional cloud services, costing as low as $4 per terabyte per month, compared to Amazon Cloud and Microsoft Azure's $16 to $23 per terabyte.

Though still in its early stages, compelling DAI use cases are emerging. In healthcare, DAI enhances data security, speeds up diagnoses, and improves treatments by analyzing medical data in real time. Blockchain ensures secure storage and quick access to patient records, enhancing care. In finance, DAI improves transaction efficiency, accuracy, and security, such as by digitizing loan documents for faster and more secure processing.

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