21 Keys to Ethereum Layer 2 and Rollups

Master the essentials of Ethereum scaling, Layer 2 and Rollups.

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Arbitrum One Chain

An optimistic rollup Layer 2 for Ethereum, leading in DeFi TVL with advanced governance features.

Arbitrum One, live since 2021, batches up to 40,000 TPS off-chain with 250ms block times, securing $15 billion TVL through fraud-proof challenges resolvable in 7 days. It has $300 million quarterly revenue from fees.

This L2 chain supports 800+ dApps, including GMX for perpetuals trading $500 million daily volume, and integrates Stylus for Rust/WASM contracts deployed since 2024.

Base Chain

Coinbase's Ethereum Layer 2 network built on the OP Stack, optimized for on-chain applications and developer accessibility.

Base Chain, launched in August 2023, is an optimistic rollup processing 100 million monthly transactions at sub-cent fees, leveraging Coinbase's infrastructure for 99.9% uptime. It supports seamless bridging of $5 billion in assets from Ethereum.

As part of the OP Superchain, Base hosts 1,000+ dApps, including Aerodrome for DEX trading with $1.2 billion TVL, and explores a native token for governance. Its focus on low-cost on-ramps has driven 20% of Ethereum's L2 activity in 2025.

Blockchain Trilemma

The blockchain trilemma refers to the challenge of balancing three core properties—decentralization, security, and scalability—in a blockchain network, where optimizing one often compromises the others.

The blockchain trilemma, a concept popularized by Ethereum co-founder Vitalik Buterin, describes the trade-offs blockchain networks face in achieving three desirable attributes: decentralization, security, and scalability.

Decentralization ensures no single entity controls the network, fostering trust and censorship resistance. Security protects the network from attacks, ensuring data integrity and user funds. Scalability enables the network to handle high transaction volumes efficiently. The trilemma posits that improving one of these aspects typically weakens at least one of the others, creating a delicate balance for blockchain designers.

For example, Bitcoin prioritizes decentralization and security, with a distributed network of nodes and robust cryptographic mechanisms like proof-of-work (PoW). However, its scalability is limited, processing only about 4-7 transactions per second (TPS). Ethereum, similarly, has faced scalability challenges, though layer-2 solutions like Optimism and Arbitrum aim to address this while maintaining decentralization and security. In contrast, some newer blockchains, like Solana, achieve high scalability (up to 65,000 TPS) but face criticism for potential centralization due to high hardware requirements for validators, which can reduce node diversity.

Solutions to the trilemma include Rollups (e.g., Ethereum's roadmap), layer-2 scaling (e.g., Lightning Network for Bitcoin), or alternative consensus mechanisms like proof-of-stake (PoS),

which reduce energy costs but introduce new trade-offs. No blockchain has fully "solved" the trilemma, and projects must align their design choices with their intended use case, such as prioritizing scalability for payments or decentralization for governance.

BNB Chain (BSC)

Binance's EVM-compatible blockchain, combining high performance with community-driven governance and the CEX ecosystem.

BNB Chain, evolved from Binance Smart Chain in 2022, uses proof-of-staked-authority with 21 validators for 3-second blocks and 100 TPS, securing $5 billion TVL. Its native token is BNB token.

As of 2025, it boasts 51.6 million monthly active addresses, hosting PancakeSwap with $2 billion volume.

Celestia DA

A modular data availability network that offloads DA from Ethereum's execution layers, enabling scalable rollups with low costs.

Celestia's mainnet is live in 2023. It provides DA sampling to verify 1 MB blocks via light nodes, reducing costs by 95% to $0.05 per MB for Layer 2 rollups on Ethereum.

Integrated with 20+ rollups like Dymension, Celestia handles 10 GB/s throughput, preventing data withholding through erasure coding and fraud proofs.

DA (Data Availability)

DA is the mechanism ensuring rollup transaction data is accessible on Ethereum, preventing withholding attacks and enabling verification.

In Ethereum rollups, data availability (DA) requires posting compressed transaction data—typically 16-32 KB per block—to the Layer 1 chain, which is Ethereum mainnet. This allows light clients to reconstruct states without trusting operators.

Post-Dencun upgrade in 2024, blobs provide 384 KB per block at 0.75 Ggas cost, reducing fees by 90% for rollups like Optimism. Rollups can opt for Ethereum's external DA layer like Celestia, but Ethereum-native DA ensures censorship resistance.

EVM-Compatible Chain

A blockchain network designed to execute Ethereum Virtual Machine (EVM) bytecode, enabling direct compatibility with Ethereum smart contracts and tools.

EVM-compatible chains replicate the Ethereum Virtual Machine environment, allowing developers to deploy Ethereum-based decentralized applications (dApps) and digital assets without modifications.

Examples include BNB Chain and Polygon, which provide faster speeds and lower fees—often under $0.01 per transaction—compared to Ethereum's mainnet, where costs can exceed $1 during peak times. This compatibility supports standards like ERC-20 for tokens and ERC-721 for NFTs, fostering seamless cross-chain interactions.

As of 2025, over 50 EVM-compatible chains exist, collectively processing billions in daily transaction value, with Avalanche achieving up to 4,500 TPS through its subnet architecture. These chains enhance Ethereum's scalability by distributing load while maintaining bytecode-level equivalence for tools like MetaMask wallets.

EVM (Ethereum Virtual Machine)

A decentralized computation engine that executes smart contracts on the Ethereum blockchain.

The Ethereum Virtual Machine (EVM) is a Turing-complete virtual machine embedded in every Ethereum node, responsible for executing smart contract code.

It provides a sandboxed environment where smart contracts, written in languages like Solidity, are compiled into bytecode and run deterministically across the network. The EVM ensures that all nodes reach the same state after executing a contract, enabling trustless and decentralized computation. Gas fees, paid in ETH, limit the computational resources used by the EVM to prevent abuse and ensure network efficiency.

L2BEAT

An analytics platform tracking Ethereum Layer 2 scaling solutions, providing metrics on TVL, risks, and adoption.

L2BEAT monitors 50+ Ethereum L2 projects, displaying real-time data like $40 billion total TVL and 1.2 million daily transactions As of 2025. It evaluates risks via stages (Stage 0-2), with only Arbitrum and Optimism at Stage 2 for full decentralization.

The open-source tool uses TypeScript for dashboards comparing sequencer uptime (e.g., 99.5% average) and upgradeability, aiding developers in assessing protocol maturity.

Layer 1 (L1)

The foundational blockchain protocol handling consensus, security, and transaction execution, like Bitcoin or Ethereum.

Layer 1 (L1) blockchains are base networks executing all transactions natively, using consensus like PoW or PoS to validate blocks.

Ethereum, post-2022 Merge, uses PoS with 32 ETH staking for validators, processing 15-30 TPS at 1.5 gwei fees. Other examples include Solana (50,000 TPS via Proof-of-History), Avalanche (4,500 TPS sharding), and Polkadot (1,000 TPS parachains), with L1 market cap at $3.3 trillion in 2025. Scaling via code upgrades like Ethereum's Dencun (2024) cuts L2 fees 90%.

L1s prioritize decentralization—Bitcoin's 15,000 nodes—but face trilemma trade-offs, with energy use (Bitcoin: 150 TWh/year) versus speed, underpinning 70% of DeFi's $100 billion TVL.

Layer 2

Secondary protocols built atop Layer 1 blockchains to enhance scalability by offloading computations while inheriting security.

Layer 2 (L2) solutions process transactions off-chain, batching them for L1 settlement—e.g., Lightning Network on Bitcoin enables 1 million TPS at <1 satoshi fees for micropayments. Ethereum L2s like Arbitrum handle 40,000 TPS, reducing fees to $0.01 from L1's $1+.

Layer 2 types include rollups (ZK/Optimistic), state channels (Raiden), and sidechains (Polygon), with $40 billion TVL in 2025. ZK-rollups use proofs for instant finality, while Optimistic assume validity with 7-day challenges.

L2s address L1 bottlenecks—Ethereum's 15 TPS—boosting adoption, though interoperability via bridges risks exploits ($2 billion lost 2022-2024), fostering 80% of new dApps.

Linea Chain

Consensys' zero-knowledge Ethereum Layer 2 rollup, emphasizing privacy and ETH economy strengthening through burn mechanics.

Linea, launched in 2023, uses zkEVM technology to prove transactions in under 1 minute, supporting 1,000 TPS and fees below $0.005 while generating $65 million in revenue for Consensys by 2025. It burns 100% of sequencer fees in ETH, distributing yields to stakers holding over 500,000 ETH.

The chain's community token airdrop of 9.4 billion LINEA tokens in September 2025 incentivizes adoption, with TVL reaching $2.5 billion across DeFi protocols like Pendle. Linea's x402 expansion integrates with Consensys tools for enterprise-grade privacy.

OP Mainnet

Optimism's optimistic rollup network for Ethereum, delivering low-cost, high-speed transactions.

OP Mainnet, launched in 2021 by OP Labs, is an EVM-equivalent optimistic rollup that batches transactions off-chain and posts data to Ethereum. It uses fraud proofs with a 7-day challenge window, securing over $10 billion in TVL and processing 50 million monthly transactions as of 2025.

As the core of the Optimism ecosystem, OP Mainnet powers dApps like Uniswap, with single-round fault proofs reducing confirmation times to 1 hour post-2024 upgrades. Its open-source nature has spawned 20+ chains in the Superchain.

OP Stack and OP Superchain

The modular, open-source framework for building Ethereum Layer 2 chains, forming the interconnected Superchain ecosystem.

The OP Stack is a standardized toolkit for deploying optimistic rollups, including components like op-node for sequencing and Bedrock for EVM execution, enabling chains with 100ms latency. Used by over 25 chains, it supports shared bridges and governance via the Optimism Collective, which holds 19% of OP tokens for funding.

The OP Superchain connects these chains via a unified communication layer, allowing atomic cross-chain swaps and shared liquidity pools exceeding $20 billion TVL in 2025. It emphasizes Ethereum-grade security through collective sequencer sets and fault-proof systems.

Polygon PoS Chain

Polygon's proof-of-stake sidechain that parallels Ethereum, offering high-throughput transactions secured by its own validators.

Polygon PoS Chain, launched in 2020, is an EVM-compatible sidechain using proof-of-stake consensus with 100 validators staking over 1.9 million POL(formerly MATIC) tokens as of 2025. Unlike true Layer 2 rollups, Polygon PoS operates independently.

Rollup

A rollup is a layer-2 scaling solution for Ethereum that processes transactions off-chain while leveraging Ethereum's main chain for security and data availability, improving scalability and reducing costs.

Rollups are a type of layer-2 scaling solution designed to enhance Ethereum's transaction throughput and reduce gas fees while maintaining the network's decentralization and security. They work by processing and bundling (or “rolling up”) hundreds or thousands of transactions off-chain into a single batch, which is then submitted to Ethereum's layer-1 main chain for verification and data storage. This approach significantly reduces the computational load on Ethereum, enabling faster and cheaper transactions without sacrificing the main chain's security guarantees.

There are two main types of rollups: Optimistic Rollups and ZK-Rollups (Zero-Knowledge Rollups). Optimistic Rollups, such as Arbitrum and Optimism, assume transactions are valid by default but allow a challenge period (typically 7 days) during which invalid transactions can be disputed via fraud proofs. They are widely used due to their compatibility with Ethereum's Virtual Machine (EVM), enabling developers to deploy existing smart contracts easily. For example, Arbitrum One has processed over 1 billion transactions as of 2025, significantly alleviating Ethereum's congestion.

ZK-Rollups, like zkSync and Starknet, use cryptographic zero-knowledge proofs to validate transactions instantly, offering faster finality but requiring more complex computation. Both types store transaction data on Ethereum's layer-1, ensuring data availability and security.

Rollups have become critical to Ethereum's scalability roadmap, complementing upgrades like sharding. They enable applications like decentralized finance (DeFi) and NFT marketplaces to handle higher transaction volumes at lower costs—often reducing fees from tens or hundreds of dollars to cents. However, rollups rely on sequencers (nodes that order transactions), which can introduce centralization risks, and users may face delays when withdrawing funds back to layer-1. Despite these trade-offs, rollups are a cornerstone of Ethereum's ecosystem, processing millions of transactions daily while preserving the network's core principles.

Based Rollup (L1-sequenced)

A based rollup is a layer-2 scaling solution for Ethereum that uses the layer-1 blockchain's validators for transaction sequencing, enhancing decentralization and alignment with Ethereum's security model.

Based rollups, also known as L1-sequenced rollups, are a specialized type of Ethereum layer-2 solution where transaction ordering and sequencing are handled directly by Ethereum's layer-1 validators rather than a dedicated, often centralized sequencer.

Proposed by Ethereum Foundation researcher Justin Drake in March 2023, this approach inherits Ethereum's liveness guarantees, censorship resistance, and decentralization, addressing key pain points in traditional rollups like potential sequencer failures or MEV (maximum extractable value) capture by single entities. Transactions enter the shared mempool visible to Ethereum's searchers, builders, and proposers, who include them in L1 blocks permissionlessly, ensuring no special permissions are needed and aligning the rollup's block order with Ethereum's.

This model promotes synchronous composability across based rollups, allowing smart contracts on different L2s to interact in near-real-time within the same Ethereum block, reviving Ethereum's "money legos" vision for seamless DeFi interoperability without asynchronous bridges. Economically, based rollups route MEV back to Ethereum validators, reducing costs by eliminating sequencer signature overheads and fostering better incentive alignment—for instance, Taiko, the first based rollup to launch its mainnet in June 2024, returns approximately five times more revenue to Ethereum than centralized sequencer

rollups like Base or Arbitrum. Taiko, built as a Type-1 zkEVM, processes transactions off-chain using zero-knowledge proofs while leveraging Ethereum's sequencing, achieving up to 100,000 TPS in tests and fees under $0.01, with over 1 million active addresses and $500 million in TVL as of 2025.

This design addresses Ethereum's layer-2 fragmentation by realigning L2s with L1, potentially enabling up to thousands of transactions per second with fees as low as fractions of a cent, as seen in prototypes like Ethrex's upcoming based rollup mode. However, based rollups may face challenges like dependency on L1 block times for sequencing, which could limit speed compared to centralized sequencers, though innovations in preconfirmation tech, as in Puffer, aim to make withdrawals near-instant.

Optimistic Rollup

An Optimistic Rollup is a layer-2 scaling solution for Ethereum that processes transactions off-chain, assumes they are valid, and posts compressed data to the main chain, relying on fraud proofs to ensure correctness.

Optimistic Rollups are a type of layer-2 scaling solution designed to increase Ethereum's transaction throughput and reduce gas fees while leveraging the main chain's security and decentralization. They operate by executing transactions off-chain in a separate environment, bundling (or “rolling up”) thousands of transactions into a single batch, and submitting a compressed summary to Ethereum's layer-1 blockchain.

Unlike ZK-Rollups, which use cryptographic proofs for validation, Optimistic Rollups assume transactions are valid by default (“optimistic”) but include a challenge period—typically 7 days—during which anyone can submit fraud proofs to dispute invalid transactions. If a fraud proof is verified, the incorrect state is reverted, ensuring security.

Key implementations include Arbitrum and Optimism. Arbitrum One, for instance, has processed over 1.2 billion transactions as of 2025, significantly reducing costs for users (e.g., fees as low as $0.10 compared to Ethereum's $1-$50). These rollups are EVM-compatible, allowing developers to deploy existing Ethereum smart contracts with minimal changes, making them popular for DeFi and NFT applications. Data availability is maintained by posting transaction data or compressed state updates to Ethereum's layer-1, ensuring transparency and auditability.

However, Optimistic Rollups have trade-offs. The challenge period delays withdrawals to the main chain, which can frustrate users needing fast liquidity. Additionally, reliance on centralized

sequencers for transaction ordering introduces potential risks, though decentralized sequencer designs are being explored. Despite these challenges, Optimistic Rollups are a cornerstone of Ethereum's scaling ecosystem, handling millions of transactions daily while preserving the network's security and reducing costs by up to 100x compared to layer-1.

ZK-Rollup

A ZK-Rollup is a layer-2 scaling solution for Ethereum that processes transactions off-chain and uses zero-knowledge proofs to validate them, posting compact data to the main chain for security and finality.

ZK-Rollups (Zero-Knowledge Rollups) are a layer-2 scaling solution designed to enhance Ethereum's scalability by processing thousands of transactions off-chain and submitting a single, compressed proof to Ethereum's layer-1 blockchain. Unlike Optimistic Rollups, which assume transaction validity and rely on fraud proofs, ZK-Rollups use cryptographic zero-knowledge proofs (specifically, validity proofs like zk-SNARKs or zk-STARKs) to mathematically verify the correctness of off-chain transactions. This proof, along with minimal transaction data, is posted to Ethereum, ensuring security and data availability while significantly reducing gas fees and increasing throughput.

Prominent ZK-Rollup implementations include zkSync, Starknet, and Scroll. For example, zkSync Era has processed over 500 million transactions as of 2025, with fees often below $0.05, compared to Ethereum mainnet fees of $1-$50. ZK-Rollups offer faster transaction finality than Optimistic Rollups, as there's no challenge period—once the proof is verified on layer-1, transactions are settled instantly. They are particularly suited for high-throughput applications like DeFi, payments, and tokenized asset trading. However, ZK-Rollups are computationally intensive, requiring significant resources to generate proofs, and full EVM compatibility has been challenging, though projects like zkSync and Scroll have made strides toward supporting Ethereum's Virtual Machine.

Despite their efficiency, ZK-Rollups face trade-offs. The complexity of zero-knowledge cryptography can limit developer accessibility, and centralized sequencers (used to order transactions) pose potential centralization risks, though decentralized alternatives are in development. ZK-Rollups store transaction data or state diffs on Ethereum's layer-1, ensuring auditability, but generating proofs can be costly for low-transaction volumes. As part of Ethereum's scaling roadmap, ZK-Rollups are pivotal, enabling up to 100,000 transactions per second while maintaining Ethereum's security, making them a powerful tool for scaling decentralized applications.

Unichain

Uniswap's high-speed Layer 2 blockchain optimized for DeFi liquidity and cross-chain interoperability.

Unichain, mainnet-launched February 2025, achieves 200ms sub-blocks via Flashblocks in TEEs, enabling 1-second finality and $1 billion TVL within months. Built on OP Stack, it supports atomic swaps across Superchain chains, reducing latency by 90% for DEX trades.

Focused on DeFi, Unichain hosts Uniswap v4 with hooks for custom liquidity, processing $500 million daily volume and integrating 20+ bridges for seamless asset transfers.

ZKsync Era Chain

Matter Labs' zero-knowledge rollup Layer 2 for Ethereum, focusing on elastic scaling and privacy-preserving transactions.

ZKsync Era, mainnet since 2023, uses zkEVM to validate 2,000 TPS batches in 5 minutes, with fees at $0.001 and $3 billion TVL in DeFi apps like SyncSwap. Its ZK token, launched in 2024, enables governance with 3.7 billion supply. The network's account abstraction allows gasless transactions via paymasters, processing 100 million monthly ops, and integrates with Ethereum via native bridges for 99% finality.

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