Layer 2 Scaling Solutions

A Five-Minute Overview

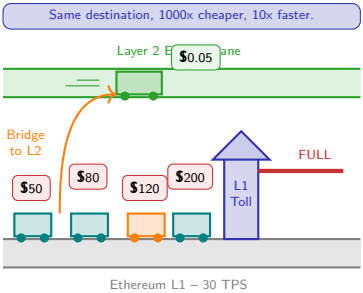
BSc Blockchain Course

Why Can't Ethereum Handle All Its Transactions?

Ethereum processes roughly 15–30 transactions per second. That is adequate when the network is quiet, but during periods of high demand – an NFT mint, a DeFi farming launch, a market crash – users compete for block space by bidding up gas fees. A simple token swap that costs $2 on a calm day can spike to $50 or more during congestion. **Three symptoms of the congestion problem:**

- **Throughput ceiling:** ∼30 TPS regardless of demand – every block is full during peaks
- **Gas fee spikes:** Users bid against each other in a first-price auction for inclusion, pushing fees to hundreds of dollars per transaction
- **Priced-out users:** Small transactions become uneconomical – a $10 swap with a $50 fee makes no sense

Layer 2 solutions move transaction execution off-chain while inheriting Ethereum's security – like building an express lane above a congested highway.



Layer 2 solutions execute transactions off Ethereum's main chain but post proofs back to L1, inheriting its security guarantees while achieving higher throughput and lower fees.

Source: Ethereum.org (2024). "Scaling." ethereum.org/en/developers/docs/scaling; L2Beat (2024). l2beat.com/scaling/summary

What's Different Between L1 and L2?

Three execution models compared across five dimensions:

Property	L1 (Ethereum)	Optimistic Rollup	ZK Rollup
Security model	Full consensus	Fraud proofs	Validity proofs
TPS	∼30	∼2,000–4,000	∼2,000–10,000
Avg. tx cost	$1–$50+	$0.01–$0.10	$0.01–$0.20
Finality	∼12 min	7 days (challenge)	Minutes (proof)
EVM compatible?	Native	Yes (OP Stack, Arbitrum)	Partial (growing)

Pattern to notice:

Both rollup types compress hundreds of transactions into a single L1 posting. The difference is *how* they prove correctness. Optimistic rollups assume transactions are valid and allow a 7-day challenge window. ZK rollups generate a cryptographic proof that the batch is correct – finality is faster but proof generation is computationally expensive. *Both approaches inherit Ethereum's security: if L1 is secure, the rollup is secure.*

The key question each model answers:

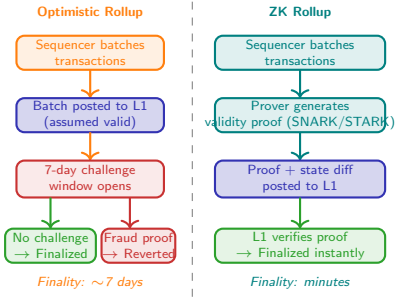
- **Ethereum L1:** "Is every node re-executing this transaction?"
  Full security, full cost. Every validator independently verifies every transaction.
- **Optimistic Rollup:** "Did anyone challenge this batch in 7 days?"
  Transactions are assumed valid unless a challenger submits a fraud proof. Cheap execution, delayed finality.
- **ZK Rollup:** "Does the mathematical proof verify?"
  A succinct proof guarantees correctness of the entire batch. Fast finality, expensive proof generation.

The tradeoff: optimistic rollups are easier to build; ZK rollups offer faster finality. Both are far cheaper than L1.

Rollups do not weaken Ethereum's security – they outsource execution while posting compressed data and proofs back to L1. The chain of trust always terminates at Ethereum's consensus layer.

Source: Vitalik Buterin (2021). "An Incomplete Guide to Rollups." vitalik.eth.limo; L2Beat (2024). l2beat.com

Who Verifies – The Chain, A Prover, or A Challenger?



Two philosophies of trust:

- **Optimistic:** "Trust but verify." Transactions are posted to L1 and assumed correct. Anyone can submit a fraud proof during the 7-day window. If no one challenges, the batch is finalized. The security assumption is that *at least one honest watcher* exists.
- **ZK (Zero Knowledge):** "Prove then trust." A cryptographic proof mathematically guarantees that the batch of transactions was executed correctly. L1 only needs to verify the proof – not re-execute any transaction. Finality is immediate upon proof verification.

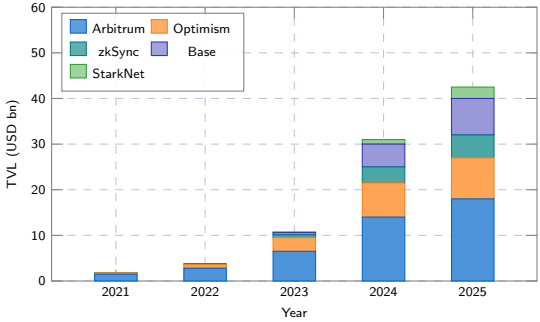
Key tradeoff: Optimistic rollups are simpler to build and fully EVM-compatible today. ZK rollups offer stronger guarantees and faster finality but require complex proof-generation hardware.

Optimistic rollups rely on game theory (someone will challenge fraud); ZK rollups rely on mathematics (the proof is either valid or it is not). Both derive final security from Ethereum L1.

Source: Buterin, V. (2021). "An Incomplete Guide to Rollups"; Ethereum Foundation (2024). "Optimistic vs ZK Rollups." ethereum.org

Why Are Billions Moving to Layer 2?

Layer 2 Total Value Locked – illustrative growth (USD billions):



Illustrative values based on L2Beat and DefiLlama data. Not investment advice.

What drove each phase:

- **2021–2022 – Early adopters:**
  Arbitrum and Optimism launched as the first production rollups. DeFi power users migrated to escape high L1 gas fees. TVL grew from near zero to several billion.
- **2023 – ZK rollups arrive:**
  zkSync Era and StarkNet mainnet launched. Base (Coinbase's L2) brought millions of new users through a familiar onramp. Competition drove fees even lower.
- **2024–2025 – Mass adoption:**
  EIP-4844 (proto-danksharding) reduced L2 data posting costs by 10–100x. Total L2 TVL exceeded **$**40B. More transactions now occur on L2s than on Ethereum L1 itself.

The trend is clear: execution is moving to L2; Ethereum L1 is becoming a settlement and data-availability layer.

Layer 2 TVL has grown from under **$**2B in 2021 to over **$**40B in 2025, driven by lower fees, broader EVM compatibility, and Ethereum's own roadmap pushing execution off L1.

Source: L2Beat (2024). l2beat.com/scaling/tvl; DefiLlama (2024). defillama.com/chains; EIP-4844 specification.

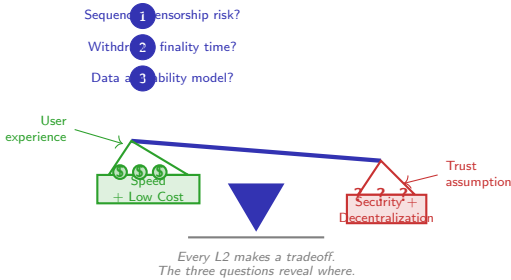
Three Questions That Reveal Any L2's True Design

Before trusting any Layer 2 with your assets, apply these three questions in order: **Question 1: Can the sequencer censor or reorder your transactions?**

Most L2s today rely on a single sequencer operated by the team. If that sequencer goes down or censors transactions, users may be unable to exit. Look for: forced inclusion mechanisms, decentralized sequencer plans, and escape hatches to L1. **Question 2: How long until your withdrawal is final on L1?**

Optimistic rollups impose a 7-day challenge period before funds can be withdrawn to L1. ZK rollups finalize in minutes once the proof is verified. Fast withdrawal bridges exist but introduce new trust assumptions. Understand the finality model before depositing. **Question 3: Where is the**

transaction data stored?
If an L2 posts full data to Ethereum, anyone can reconstruct the state. If it uses off-chain data availability (a "validium"), you trust a separate committee. Data availability determines whether you can always prove your balance and exit – even if the L2 operators disappear. *If an L2 passes all three tests, it inherits Ethereum's security. If it fails any one – you are trusting additional parties.*



The three questions are a checklist, not a guarantee: even well-designed L2s can have bugs, centralized upgrade keys, or untested escape hatches. Layer 2 shifts risk – it does not eliminate it.

Source: L2Beat Risk Analysis (2024). l2beat.com/scaling/risk; Ethereum Foundation (2024). "Layer 2 Security." ethereum.org