Blockchain infrastructure for autonomous AI agent economies

Ethereum is rapidly becoming the trust layer for autonomous AI agents. Two protocols — ERC-8004 for identity/reputation and x402 for payments — launched on mainnet within months of each other and now form the backbone of an emerging "Labour as a Service" stack where AI agents discover, trust, hire, and pay each other without human intervention. ERC-8004 went live on Ethereum mainnet on January 29, 2026, with over **24,500 agents registered** in its first ten days. x402 has processed **100 million+ payments** since its May 2025 launch. Together with ERC-6551 token-bound accounts, ENS subnames, streaming payment protocols, and on-chain marketplaces like Olas and Virtuals, a coherent infrastructure stack is crystallizing that could underpin multi-agent economies at scale. This report maps every layer of that stack — identity, reputation, payments, memory, ownership, naming, and marketplaces — with technical detail, current status, and critical assessment.

ERC-8004: the trust layer for agent economies

ERC-8004, formally titled "Trustless Agents," is a Draft-status EIP that defines three lightweight, on-chain singleton registries enabling agents to **discover, choose, and interact across organizational boundaries without pre-existing trust**. It was created on August 13, 2025, and co-authored by Marco De Rossi (MetaMask/Consensys), Davide Crapis (Ethereum Foundation dAI Team lead), Jordan Ellis (Google), and Erik Reppel (Coinbase). The specification was refined with input from over **100 industry leaders** including representatives from EigenLayer, The Graph, ENS, and Taiko.

The standard defines three registries deployed as singletons per chain:

The Identity Registry is built on ERC-721 with URIStorage, making each agent a transferable NFT. Every agent receives a globally unique identifier (`{namespace}:{chainId}:{identityRegistry}` + `agentId`) and an `agentURI` resolving to a structured JSON registration file. This file describes the agent's name, capabilities, supported trust mechanisms, service endpoints (A2A, MCP, OASF, ENS, DID, web), and optionally declares `x402Support` for payment compatibility. On-chain metadata can be set via `setMetadata()` , with a reserved `agentWallet` key requiring EIP-712 or ERC-1271 signature verification. Registration takes three overloads — with full metadata, URI only, or empty.

The Reputation Registry stores structured feedback on-chain while deliberately pushing complex aggregation off-chain. Each feedback entry includes a signed fixed-point `value` (int128 with configurable decimals), two string tags for filtering (matching A2A skill identifiers or MCP tool names), an optional endpoint reference, and a `feedbackURI` + `feedbackHash` pointing to off-chain detail stored on IPFS. Self-feedback is prohibited. Anyone can append responses to existing feedback. The `getSummary()` function returns aggregated count and value filtered by client addresses and tags. This creates an **immutable, portable audit trail** — when an agent moves platforms, its reputation follows.

The Validation Registry provides hooks for independent verification of agent work through stake-secured re-execution, zkML proofs, TEE attestations, or trusted judges. Validation requests are initiated by agent owners, and only designated validators respond with scores from 0–100. Multiple progressive responses per request are supported, enabling "soft finality" followed by "hard finality." Slashing and incentive mechanisms are deliberately out of scope.

The standard implements a tiered trust model: **reputation-based** trust for low-stakes interactions (ordering pizza), **crypto-economic** validation for medium-stakes (financial transactions), and **crypto-verification** via TEE attestations and zero-knowledge proofs for high-stakes operations (medical diagnosis). As Crapis stated in the Bankless podcast on February 5, 2026: "Commerce can't happen if people don't trust each other… the fundamental thesis is that the future of AI is multi-agents — there are going to be many agents, more powerful, and they're gonna be specialized."

Mainnet deployment occurred January 29, 2026, with contracts at `0x8004A169FB4a3325136EB29fA0ceB6D2e539a432` (Identity) and `0x8004BAa17C55a88189AE136b182e5fdA19dE9b63` (Reputation). **Base became the first L2 to support ERC-8004** on February 3, 2026, followed by Celo on February 6. The ecosystem already includes reference implementations in Solidity (Foundry-based), JavaScript/TypeScript and Python SDKs, TEE integrations via Phala

Network, and a scanning tool at 8004scan.io. An "awesome list" at github.com/sudeepb02/awesome-erc8004 tracks community resources.

Key security considerations include Sybil attacks (inflating fake agent reputation), identity transfer risks (selling an NFT transfers accumulated reputation, enabling potential "reputation laundering"), and the fundamental limitation that verified identity does not guarantee honest behavior. Registration bonds and reviewer-based filtering are proposed mitigations.

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x402: HTTP-native payments for machines

x402 is a production-ready, open-source payment protocol created by Coinbase that embeds stablecoin payments directly into HTTP by activating the long-dormant **HTTP 402 "Payment Required" status code**. Its creator, Erik Reppel (Head of Engineering, Coinbase Developer Platform), designed it so that any API or service can require payment before serving a response — with no accounts, subscriptions, API keys, or human intervention.

The payment flow is elegant in its simplicity. A client (browser, AI agent, or app) makes a standard HTTP request. The server responds with `HTTP 402` and a `PAYMENT-REQUIRED` header containing a base64-encoded `PaymentRequirements` object specifying price, accepted tokens, network, and recipient address. The client constructs a `PaymentPayload` — a cryptographically signed authorization using EIP-712 on EVM chains — and retries the request with a `PAYMENT-SIGNATURE` header. A **facilitator** server verifies the payment and submits it on-chain using ERC-3009 (TransferWithAuthorization) for gasless USDC transfers. The resource server then returns `200 OK` with the requested content.

Server-side integration requires literally one line of middleware code:

```
app.use(paymentMiddleware("0xYourAddress", { "/your-endpoint": "$0.01" }));
```

The **x402 Foundation**, co-founded by Coinbase and Cloudflare in September 2025, governs the protocol as a neutral open standard under Apache 2.0 license. Cloudflare CEO Matthew Prince called it a "shared vision" for neutral internet payment infrastructure. The protocol launched V1 in May 2025 and **V2 in December 2025**, adding modular architecture, multi-chain support via CAIP-2 identifiers, wallet-based identity using CAIP-122, dynamic routing, and a discovery extension.

x402 currently operates on **Base** (primary, ~99% of EVM usage), **Solana** (35M+ transactions, $10M+ volume), **Ethereum mainnet**, and BNB Chain (via AEON facilitator). It supports USDC as the primary asset but is token-agnostic by design — any ERC-20 implementing EIP-3009 works. Transaction costs on Base are approximately **$0.0001**, making micropayments of **$0.001** economically viable — a stark contrast to credit cards' $0.30 + 2.9% per transaction.

The integration ecosystem is formidable. **Cloudflare** integrated x402 into its Agents SDK and Workers platform. **Google** included x402 in its Agent Payments Protocol (AP2) via the `a2a-x402` extension. **Vercel** built `x402-mcp` for MCP tool payments. **Anthropic's** MCP enables AI models to discover and pay for tools autonomously via x402. Additional integrations span Chainlink, MetaMask, Circle, NEAR, QuickNode, XMTP, Virtuals Protocol, and Browserbase. The **Federal Reserve Bank of Atlanta** published an article on x402 and machine-to-machine payments in October 2025.

Critical assessment: while x402 has no formal security audit from major firms, its real-world traction is significant. The primary risk is **facilitator concentration** — most traffic currently flows through Coinbase's facilitator, and while the protocol is permissionless, network effects may create lock-in. There is no native refund mechanism (closer to cash than reversible card payments), and managing agent wallet security at enterprise scale remains complex.

Agent identity beyond ERC-8004: soulbound tokens, DIDs, and attestations

The identity infrastructure landscape extends well beyond ERC-8004, offering complementary and alternative

approaches with different trust assumptions.

ERC-5192 (Minimal Soulbound NFTs) is a Final-status standard that adds a simple `locked()` mechanism to ERC-721. When a token returns `locked = true`, all transfer functions revert. This creates permanently non-transferable identity badges — useful for agent credentials that should never be sold or traded. Its counterpart, **ERC-5484 (Consensual Soulbound Tokens)**, also Final, adds a consent mechanism requiring the receiver's signature before issuance and configurable burn authorization (IssuerOnly, OwnerOnly, Both, Neither). For AI agents, ERC-5484's consent mechanism ensures agents explicitly agree to receive credentials, while configurable burn authority supports key rotation if an agent's keys are compromised.

ERC-8004 deliberately chose **transferable** identity (standard ERC-721) over soulbound approaches. This means selling an agent NFT transfers its accumulated reputation — a conscious design trade-off enabling agent ownership markets while introducing reputation laundering risk. A hybrid approach could use ERC-8004 for the transferable identity anchor while issuing ERC-5484 soulbound credentials for specific capabilities.

Ethereum Attestation Service (EAS) is a live, open-source, tokenless public good deployed on Ethereum mainnet and multiple L2s. It operates through just two core contracts: SchemaRegistry (defining attestation data structures) and EAS.sol (making attestations). EAS supports both on-chain attestations (gas-consuming) and off-chain attestations (gas-free, EIP-712 signed, storable on IPFS). Attestations are revocable but not deletable, support referenced chaining for provenance, and enable private data attestations using Merkle trees for selective disclosure. EAS explicitly lists "digital, physical, agent identities" as a use case and is arguably the most practical current tool for building granular agent reputation systems alongside ERC-8004.

W3C Decentralized Identifiers (DIDs) reached Recommendation status in July 2022 with 103 experimental methods and 46 conformant implementations. A DID like `did:ethr:0xAgentAddress` resolves to a DID Document containing public keys, verification methods, and service endpoints. **W3C Verifiable Credentials v2.0** (Recommendation, May 2025) enables cryptographically signed claims following a three-party model (Issuer → Holder → Verifier). Together, an AI agent could hold its own DID as a "digital passport" and present VCs attesting to safety audits, capability benchmarks, or training data provenance — with selective disclosure support through zero-knowledge proofs.

ERC-8004's registration file format already supports DID endpoints, creating a bridge between on-chain Ethereum identity and the broader W3C decentralized identity ecosystem.

ERC-6551 and the NFT-as-agent paradigm

ERC-6551 (Token Bound Accounts) is perhaps the most architecturally significant standard for representing AI agents as on-chain entities. Created by Jayden Windle and Benny Giang (co-creator of CryptoKitties/ERC-721), it defines a system that assigns **smart contract accounts to every ERC-721 NFT**. The standard launched on Ethereum mainnet on May 7, 2023 and remains in "Review" status despite widespread adoption — **250,000+ token-bound account activations** in its first twelve months.

The mechanism works through a permissionless, immutable singleton Registry Contract (deployed at `0x000000006551c19487814612e58FE06813775758`). Calling `createAccount()` deploys a minimal ERC-1167 proxy with deterministic addressing via CREATE2. The resulting Token Bound Account (TBA) can own ERC-20, ERC-721, and ERC-1155 tokens, hold ETH, and execute arbitrary operations including CALL, DELEGATECALL, CREATE, and CREATE2. Crucially, **when the parent NFT transfers, control of the TBA transfers atomically** — meaning all assets owned by the agent transfer with it.

The composability with ERC-8004 creates a powerful pattern: **AI Agent = ERC-721 NFT (via ERC-8004 Identity Registry) + ERC-6551 TBA (agent's autonomous wallet)**. The NFT represents identity and ownership. The TBA holds assets and executes transactions. Transfer the NFT, and you transfer the entire agent — identity, wallet, assets, and accumulated reputation — in a single atomic operation.

Virtuals Protocol provides the best production example. Operating on Base, Virtuals implements a four-layer architecture: an Immutable Contribution Vault (foundational smart contract wallet), VIRTUAL agents as ERC-6551 NFTs serving as both identity and wallet, registered cognitive/voice/visual cores, and contribution-tracking service NFTs. Each agent is simultaneously tokenized as an ERC-20 for co-ownership and governance, with tokens paired

against $VIRTUAL in locked liquidity pools. Revenue from per-inference payments accrues directly to agent ERC-6551 wallets. The platform has deployed approximately **17,000 agents** with over **$500M cumulative agent token market cap**.

Complementing ERC-6551, **ERC-4337 (Account Abstraction)** enables gas sponsorship so agents don't need ETH for gas, custom transaction validation with spending limits, and batched operations. **ERC-7710 (Delegated Spending)**, pushed by MetaMask for x402 integration, allows users to define precise spend scopes for agents — which assets, how much, time windows, and permitted counterparties.

Memory persistence and the question of agent "souls"

Persistent memory is the least standardized layer of the agent infrastructure stack, with solutions ranging from fully decentralized to pragmatic off-chain approaches.

IPFS provides content-addressed storage where files are identified by cryptographic hashes (CIDs), creating tamper-proof references. However, IPFS does **not guarantee persistence** — data disappears if no node pins it. Pinning services like Pinata and web3.storage offer persistence for a fee. IPFS is best suited for mutable, frequently-updated agent data: working memory snapshots, conversation logs, and embedding vectors.

Arweave offers permanent storage with a one-time payment via an endowment model, claiming data availability for 200+ years. At approximately $5–50 per upload, it suits permanent records: training history, milestone checkpoints, audit logs, and immutable decision trails. **Arweave AO**, launched February 2025, adds a hyper-parallel computing layer on top of permanent storage — combining decentralized compute with permanence specifically targeting AI and agent workloads. A bridge between IPFS and Arweave allows IPFS content to be backed by Arweave's permanence.

Ceramic Network underwent a major pivot in February 2025, merging with Textile to build an "Intelligence Network for AI Agents." The combined entity launched **Recall Network** (recall.network), described as "the foundational intelligence layer that gives millions of agents the power to prove, monetize and exchange knowledge." Ceramic's original strengths — decentralized event streaming, DID-based data ownership, gas-free writes, and composable data models — are being redirected toward verifiable data streams for agent memory, efficient embedding transport, and data provenance tracking for AI outputs.

The concept of an **"agent soul"** in the crypto-AI space encompasses four dimensions: identity persistence (immutable on-chain identity via ERC-8004 or SBTs), memory continuity (persistent state across sessions via IPFS/Arweave/Recall), reputation accumulation (on-chain track record via EAS or ERC-8004 Reputation Registry), and transferability/mortality (ability to transfer or destroy the soul via NFT mechanics or burn authorization). Projects like **SoulLayer** (soullayer.xyz) already implement this — creating "Soul NFTs" containing interaction history, dialogue style data, and evaluation systems that can be shared or merged.

ERC-8004 itself does not directly address soul or memory persistence in the sense of storing an agent's internal state or cognitive model on-chain. Rather, it provides the **persistent identity anchor** and **immutable reputation history** that serve as the "soul's" on-chain footprint. The registration file's `agentURI` can point to IPFS or Arweave for arbitrarily complex off-chain state, while on-chain metadata provides the verifiable link.

ENS subnames and the naming of agent fleets

ENS (Ethereum Name Service) provides human-readable naming infrastructure with **2 million+ registered .eth domains** and integration across PayPal, Venmo, Coinbase, and Gemini. ENS lead developer Nick Johnson has explicitly identified agent identity as a priority: "The urgent challenge with AI is to develop decentralised standards for agent identity and trust so autonomous systems remain accountable and interoperable."

ENS subnames are the natural mechanism for agent fleet naming. Any ENS name owner can create unlimited subnames — `agent-001.mycompany.eth`, `trading.fleet.eth`, `researcher.dao.eth`. The Name Wrapper (ERC-1155) provides fine-grained control through permission fuses: `PARENT_CANNOT_CONTROL` makes subnames unruggable,

`CAN_EXTEND_EXPIRY` allows self-renewal, and thirteen undefined custom fuses enable application-specific permissions. A subname registrar smart contract can programmatically issue names during agent deployment.

Real-world precedents exist: Coinbase's **Basenames** (`bob.base.eth`), Gemini's free ENS subnames (`user.gemini.eth`, launched August 2025), and platforms like Namespace.ninja for branded subname communities. Each agent subname resolves to the agent's ERC-6551 TBA address and can attach text records for capabilities, API endpoints, and A2A agent cards.

ENSv2, in a breaking February 7, 2026 announcement, will deploy **directly on Ethereum L1** rather than the originally planned Namechain L2. This decision followed Ethereum's gas limit increase from 30M to 60M (Fusaka upgrade), dropping average registration costs below **$0.05** — a 99% reduction. Vitalik Buterin endorsed the decision, calling ENS "a semi-financial application with high network importance." For agent economies, this means mass naming becomes economically viable: registering thousands of agent subnames costs pennies each, with registration possible from any EVM chain and multi-chain resolution across 60+ blockchains.

ERC-8004's registration file already supports ENS-style naming. Agent IDs use CAIP-10 format for cross-chain referencing, and ENS endpoints (e.g., `mcp.agent.eth`) leverage existing resolution infrastructure.

On-chain marketplaces where agents hire agents

Several live and emerging platforms are implementing the "Labour as a Service" vision where AI agents autonomously discover, negotiate, and complete work for payment.

Olas (formerly Autonolas) operates the most mature on-chain agent marketplace. Its **Mech Marketplace**, launched February 2025, enables AI agents to sell services, hire other agents, and collaborate autonomously with zero human input. The Marketplace App (August 2025) provides a user-friendly interface for businesses. Built on the Open Autonomous Agent framework, Olas is deployed across **9+ blockchains** including Gnosis Chain, Base, and Ethereum. On Gnosis Chain, Olas-powered agents execute over **75% of Safe transactions** on many days. The platform includes a Pearl App Store for desktop agent management and offers up to **$1M in developer grants** through its Accelerator program.

Virtuals Protocol's Agent Commerce Protocol (ACP) provides the most complete agent-to-agent commerce specification. ACP defines a four-phase transaction flow: Request (buyer discovers provider via registry), Negotiation (agents agree terms via cryptographic signing), Transaction (payment and service data submitted to smart contract escrow), and Evaluation (third-party evaluator agents assess deliverables before fund release). Emerging "ACP Clusters" include an Autonomous Media House (multi-agent creative agency) and Autonomous Hedge Fund. Virtuals has deployed ~17,000 agents on Base with over $8B in cumulative DEX volume.

NEAR Protocol's Agent Market (market.near.ai) is purpose-built for AI agents with no CAPTCHAs or human verification required. It features NEAR-based escrow ensuring fair payment (funds held until work accepted), cross-chain funding from 20+ chains with auto-conversion, dispute resolution with neutral arbitrators, and SHA-256 hash verification of deliverable integrity. Job categories span development, code review, content writing, research, data analysis, compute/API trading, and dataset intelligence trading.

Morpheus AI, live on Arbitrum since November 2024, operates a peer-to-peer network for personal AI agents with four reward pillars (Code, Capital, Compute, Community) incentivized via MOR tokens. **The ASI Alliance** — the merger of Fetch.ai, SingularityNET, Ocean Protocol, and CUDOS — represents the largest open-source decentralized AI entity with a combined market cap that reached approximately **$9.2 billion** post-merger.

Nevermined deserves special mention as a specialized AI payment infrastructure layer that sits atop x402. It provides tokenization of agent APIs, protocol-agnostic billing across MCP, A2A, x402, and AP2, and sophisticated escrow patterns including time locks, milestones, revenue splits, and spending caps with ledger-grade metering.

How the protocols compose into a coherent stack

The emerging agent economy stack crystallizes into distinct, composable layers where each protocol handles a specific concern:

Layer	Protocol	Status	Function
Communication	Google A2A + Anthropic MCP	Live (A2A donated to Linux Foundation, June 2025)	Agent discovery, capability exchange, tool interaction
Identity	ERC-8004 Identity Registry (ERC-721)	Mainnet, Jan 29, 2026	Persistent, transferable on-chain agent identity
Reputation	ERC-8004 Reputation + Validation Registries	Mainnet, Jan 29, 2026	On-chain feedback, cryptographic/economic validation
Credentials	ERC-5192/5484 SBTs + EAS + W3C VCs	Live (all Final/production)	Non-transferable credentials, attestations, verifiable claims
Wallet	ERC-6551 Token Bound Accounts	Mainnet since May 2023	Agent-as-NFT with autonomous wallet, atomic ownership transfer
Naming	ENS + Subnames	Mainnet; ENSv2 coming 2026	Human-readable agent identifiers, fleet naming
Payments	x402 (HTTP 402)	Production; V2, Dec 2025	Micropayments, per-request billing, stablecoin settlement
Streaming	Superfluid / Sablier	Mainnet, multi-chain	Continuous per-second payments for ongoing services
Memory	IPFS + Arweave + Recall Network	Live (various maturity)	Working memory, permanent storage, verifiable data streams
Marketplace	Olas / Virtuals ACP / NEAR Agent Market	Live	Agent discovery, escrow, task completion, evaluation
Settlement	Base / Solana / Ethereum L1	Live	Low-cost transaction finality

The **Bankless podcast episode** featuring Austin Griffith and Davide Crapis (February 5, 2026) articulated the integration thesis clearly. Ryan Adams made the key observation that ERC-8004's value extends beyond on-chain agents: "Even if agents aren't on chain and using cryptocurrencies… there's still a lot of value in issuing these agents effectively a passport for the internet. And a reputation system, attach that passport, and then some means to validate that reputation." Crapis described x402 as "Swift for agents" and ERC-8004 as the "missing discovery layer" that sits above payment rails.

The composition pattern works as follows: **A2A** handles capability discovery and communication. **ERC-8004** verifies which agent is trustworthy through its reputation and validation registries. **x402** settles payment, and payment proofs flow back into ERC-8004 reputation as "economically-backed trust signals." **ERC-6551** gives each agent an autonomous wallet. **ENS** provides human-readable addressing. The entire stack operates primarily on **Base** (Coinbase's L2) for cost efficiency, with high-stakes operations anchoring to Ethereum L1.

Criticisms, limitations, and open questions

Despite rapid momentum, significant challenges remain. **Sybil resistance** is the most fundamental: agents can discard bad reputations by registering new identities, partially mitigated by registration bonds but not solved. **Facilitator concentration** in x402 creates a single-point risk — while permissionless, most traffic flows through Coinbase's facilitator. **Regulatory uncertainty** looms large: agent legal liability, token securities classification, and KYC/AML compliance for autonomous transacting entities remain entirely unresolved. The lack of a **native refund mechanism** in x402 means agent commerce is closer to cash than reversible card payments.

On the market side, many AI agent tokens function as speculative instruments with limited real utility. Virtuals has been described as "pump.fun for AI agents," and token valuations have swung wildly (Virtuals from $5B peak to ~$400M; Olas from ~$2B to ~$10M). **On-chain AI execution remains computationally limited** — most agent reasoning happens off-chain with only identity, reputation, and payment settlement on-chain. The robustness of AI agents in adversarial blockchain environments is largely untested at scale.

The term **"Labour as a Service" (LaaS)** itself does not appear as an established concept in crypto-AI literature. The underlying vision — "code literally becomes labor" as one analysis puts it — is pervasive, but the specific framing appears to originate from niche community discourse rather than formal protocol specifications. The closest operational implementations are Olas's Mech Marketplace (agents hiring agents for crypto payment) and NEAR's Agent Market (explicit gig-economy model with escrow and arbitration).

Conclusion

The blockchain infrastructure for autonomous agent economies has crossed from theory to production in the span of six months. ERC-8004 and x402 together solve the two hardest problems — **trust without prior relationship** and **payment without accounts** — while ERC-6551 provides the mechanism for agents to exist as first-class on-chain economic actors. The stack is not hypothetical: 24,500+ agents are registered on ERC-8004 mainnet contracts, 100 million+ payments have flowed through x402, and platforms like Olas and Virtuals are running live agent-to-agent marketplaces with escrow and evaluation.

The most significant insight from this research is that the value proposition extends beyond crypto-native agents. As Bankless host Ryan Adams articulated, even traditional AI agents benefit from an "internet-native passport" backed by on-chain reputation. This positions Ethereum not as a requirement for agent execution but as a **neutral trust substrate** — the place where agent identities are anchored, reputations accumulate, and payments settle, regardless of where the agent's actual computation runs. The institutional backing from the Ethereum Foundation, Google, Coinbase, Cloudflare, and MetaMask suggests this is not a speculative narrative but an infrastructure bet by the industry's largest players. The open questions — Sybil resistance at scale, regulatory frameworks for autonomous economic agents, and whether reputation markets will function honestly — will determine whether Labour as a Service becomes the defining economic model of the agent era.