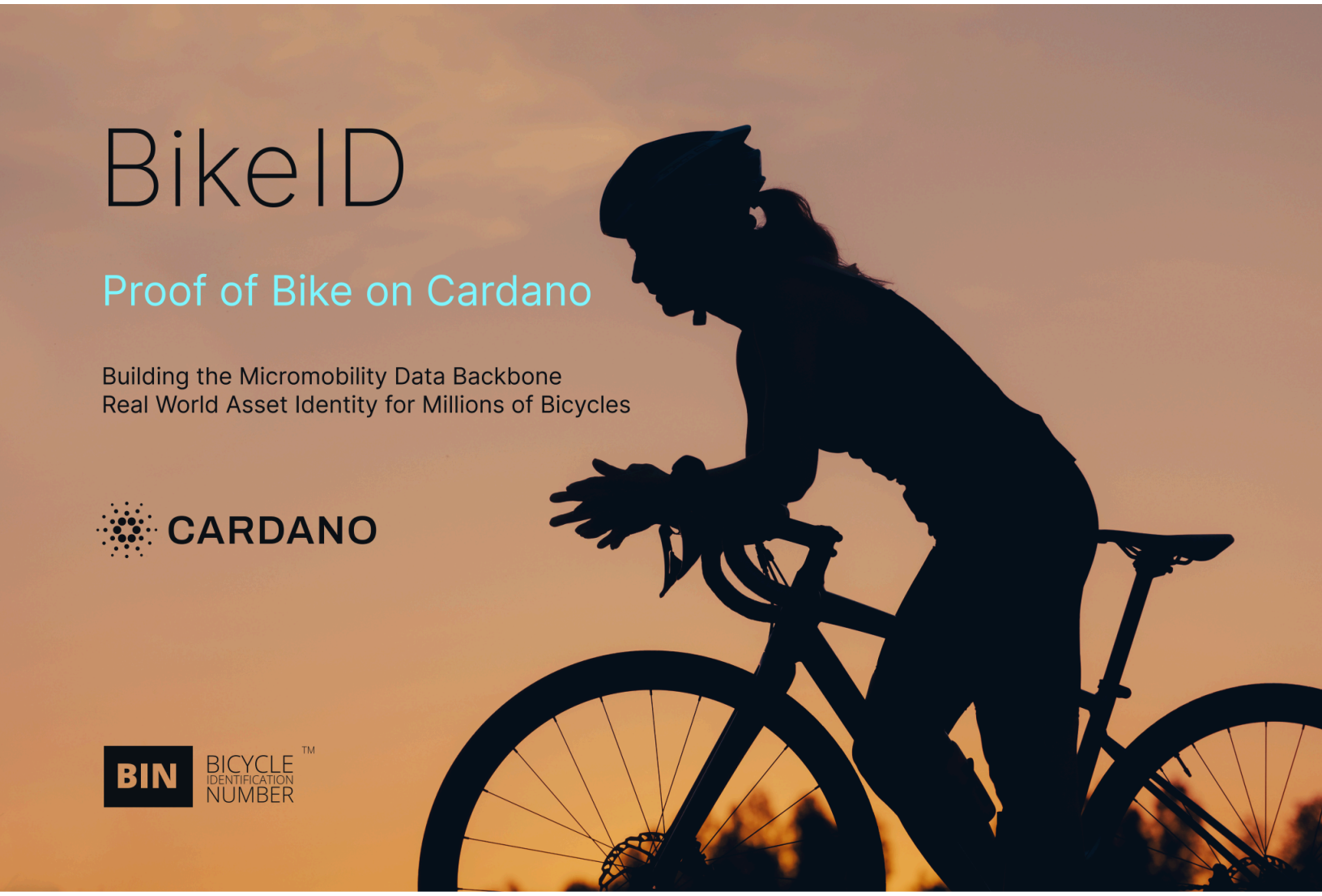

BikeID: Proof of Bike on Cardano

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By Maciej Kostecki (CTO) and Bartek Czerwiński (COO)
Trebiada Sp. z o.o., BikeID Project Team

Web: https://bikeid.org
X: https://x.com/BikeIDNumber

1. Executive Summary

The global cycling industry exceeds €70 billion annually and is projected to reach €135 billion by 2030. Despite this scale, bicycles lack a standardized identity equivalent to the Vehicle Identification Number (VIN) used in the automotive sector. The absence of such an identifier creates systemic inefficiencies: theft recovery rates below 10%, suppressed resale value, fragmented service records, and one-time sales models that prevent brands from generating recurring revenue.

BikeID introduces the Bicycle Identification Number (BIN), a universal, immutable digital identity anchored on the Cardano blockchain. Each registered bicycle is associated with two complementary proofs:

- **Proof of Bike (PoB):** a permanent, tamper-proof digital record of the bicycle's identity.
- **Proof of Bike Ownership (PoBO):** a cryptographically verifiable record of legal ownership and transfers throughout the lifecycle.

Anchoring BIN, PoB, and PoBO on Cardano ensures immutability, scalability, and cost efficiency. Off-chain integrations with partners: Iagon (decentralized storage), Midgard (interoperability), UTXSO (UTXO orchestration), and uVerify (fraud prevention and compliance), maintain performance while meeting GDPR, MiCA, and EU Product Passport requirements.

For manufacturers and retailers, BikeID restores customer retention and enables recurring revenues via warranties, service, financing, and insurance. For riders, it secures ownership, reduces theft risk, and increases second-hand value. For Cardano, it represents a flagship Real World Asset (RWA) application, demonstrating blockchain's utility in consumer markets and driving sustained adoption.

2. Introduction: The Industry Gap

2.1 Problem Definition

The absence of a universal identity system for bicycles results in:

- **Theft and Recovery Challenges:** Over 3 million bicycles are stolen annually in Europe, with recovery rates under 10%. Stolen bikes can be easily resold or dismantled without verifiable identities.
- **Supply Chain Inefficiencies:** Frame numbers are inconsistent, tamperable, and incompatible across manufacturers. This complicates recalls, warranties, and authenticity verification.
- **Suppressed Secondary Market:** Without transparent service histories, resale value collapses, discouraging financing and insurance.

- **Fragmented Ecosystem:** Manufacturers lose visibility after the initial sale, limiting opportunities for aftersales revenue and customer retention. For brands, the problem is even bigger:
    - **No recurring revenues** → once a bike is sold, the relationship ends. No service, captive finance and insurance, or upgrade revenues flow back to the manufacturer.
    - **Low customer retention** → riders drift to third-party shops and resale platforms. Brands lose visibility and loyalty.
    - **No data feedback loop** → usage, service, and lifecycle insights vanish, blocking innovation and new business models.

BikeID fixes this and highlights that this isn't just a niche problem—it's a systemic one affecting urban mobility, sustainability efforts, and economic value in a growing green transportation sector.

2.2 The Opportunity

BikeID establishes a **Bicycle Identification Number (BIN)** as a global standard. Anchored immutably on Cardano, the BIN forms the basis for:

- **Identity assurance (PoB):** secure, tamper-proof digital twin of the bicycle.
- **Ownership assurance (PoBO):** transparent, auditable record of owners and transfers.
- **Lifecycle assurance:** warranties, service, upgrades, and recalls linked to the BIN.

2.3 Building the Micromobility Data Backbone

BikeID is not only a system for registering bicycles; it is designed as the **Micromobility Data Backbone** for manufacturers, brands, retailers, insurers, financiers, riders and municipalities. By anchoring identities and ownership proofs on Cardano, and linking them to distributed data services, BikeID creates a trusted digital infrastructure where every transaction in a bicycle's lifecycle can be recorded, verified, and utilized.

The backbone consists of three coordinated layers:

1. **Proof of Bike**
    - Immutable anchoring of the Bicycle Identification Number (BIN), Proof of Bike (PoB), and Proof of Bike Ownership (PoBO).
    - Enforced via Plutus smart contracts and decentralized identifiers (Atala PRISM).
    - Provides the foundational trust layer for all subsequent lifecycle events.

2. **Lifecycle Events**
    - Service, resale, insurance, leasing, and distribution events are logged through **Iagon's decentralized storage**.
    - Interoperability will be enabled via **Midgard Protocol**, allowing data to flow across insurers, OEMs, and marketplaces.

    - **uVerify** will ensure fraud prevention, compliance, and secure verification of ownership claims.

3. **Public Data - Reference Layer**
    - Non-sensitive data such as specifications, EAN codes, images, and theft/recovery status is accessible through **AWS-backed infrastructure** for scalability and redundancy.
    - This layer ensures broad accessibility for consumers, marketplaces, and public stakeholders without compromising security or privacy.

By integrating these layers, BikeID creates a **single, verifiable source of truth** for bicycles and related services. The architecture scales horizontally, capable of supporting millions of bikes and billions of lifecycle events, while remaining cost-efficient through its hybrid on-chain/off-chain model. This framework aligns with European Union initiatives on **Digital Product Passports** and **Battery Passports**, enabling compliance while delivering economic efficiency and sustainability benefits.

3. System Architecture

BikeID employs a hybrid architecture in which **Cardano Layer 1 (L1)** provides immutable anchoring of bicycle identities and ownership records, while **Layer 2 (L2)** solutions handle high-frequency or mutable lifecycle data with cryptographic commitments back to the blockchain. This ensures both long-term trust and operational scalability.

3.1 Layer 1 - Cardano Blockchain

- **Bicycle Identification Number (BIN):** Each bicycle is assigned a unique 24-character BIN, hashed and permanently registered on-chain.
- **Proof of Bike (PoB):** Immutable, tamper-proof record of the bicycle's identity.
- **Proof of Bike Ownership (PoBO):** State machine recording ownership, transfers, liens, theft status, repossessions, and end-of-life events.
- **Plutus Smart Contracts:** Govern lifecycle logic, ensuring that ownership transitions and encumbrances follow predefined, verifiable rules.
- **uVerify Certificates:** Lifecycle events (e.g., transfers, insurance liens, recycling) are accompanied by **custom certificates** issued by ecosystem participants and anchored to the BIN. These certificates provide verifiable attestations that replace the role previously envisioned for Atala PRISM.

3.2 Layer 2 - Extensions and Data Infrastructure

- **Iagon (Decentralized Storage):** Maintains service logs, warranties, sensor data, and usage metrics. Only hashes are committed on-chain, ensuring data integrity while preserving GDPR compliance.

- **Midgard (Layer 2 Scaling):** Provides a **low-cost, Cardano-compatible L2 environment** for high-frequency lifecycle events and updates, reducing costs and congestion on L1.
- **UTxO:** Abstracts complex UTXO workflows, enabling seamless onboarding for retailers and manufacturers without requiring deep blockchain expertise.
- **uVerify (Verification Layer):** Issues, validates, and manages **custom digital certificates** linked to BIN events, ensuring that claims (ownership, insurance, recycling) are signed and verifiable by trusted parties.

3.3 3.3 L1 ↔ L2 Integration

The architecture separates immutable identity and ownership guarantees (anchored on Cardano L1) from dynamic, high-volume lifecycle data (managed on L2 and decentralized storage). This division ensures both security and efficiency.

- **Cardano Layer 1 (L1)**
    - Anchors the Bicycle Identification Number (BIN) and associated Proof of Bike (PoB) and Proof of Bike Ownership (PoBO).
    - Stores minimal but critical data — the Merkle root of each shard registry, event hashes, and certificate references.
    - Provides immutability and consensus security, ensuring that once registered, a bicycle's identity and ownership history cannot be altered.
- **Layer 2 (Midgard) and Decentralized Storage (Iagon)**
    - Handle frequent or data-heavy events, such as service logs, warranty claims, insurance updates, GPS telemetry, and recycling certificates.
    - Operate at lower cost than L1, while remaining verifiable via hash commitments stored on Cardano.
    - Support privacy controls — sensitive data remains encrypted off-chain, with only verifiable commitments exposed publicly.

- **Commitment Scheme**
    - Every lifecycle event (transfer, lien, service record) generates a uVerify certificate and/or event bundle stored off-chain.
    - A Merkle root or event hash is written to Cardano, linking the off-chain record to the immutable L1 identity.
    - This guarantees that off-chain records are tamper-evident and can always be cryptographically verified against on-chain anchors.

This hybrid model achieves the best of both layers: Cardano provides permanence and trust, while L2 and storage layers deliver scalability and privacy, enabling the system to support millions of assets and billions of lifecycle events at consumer scale.

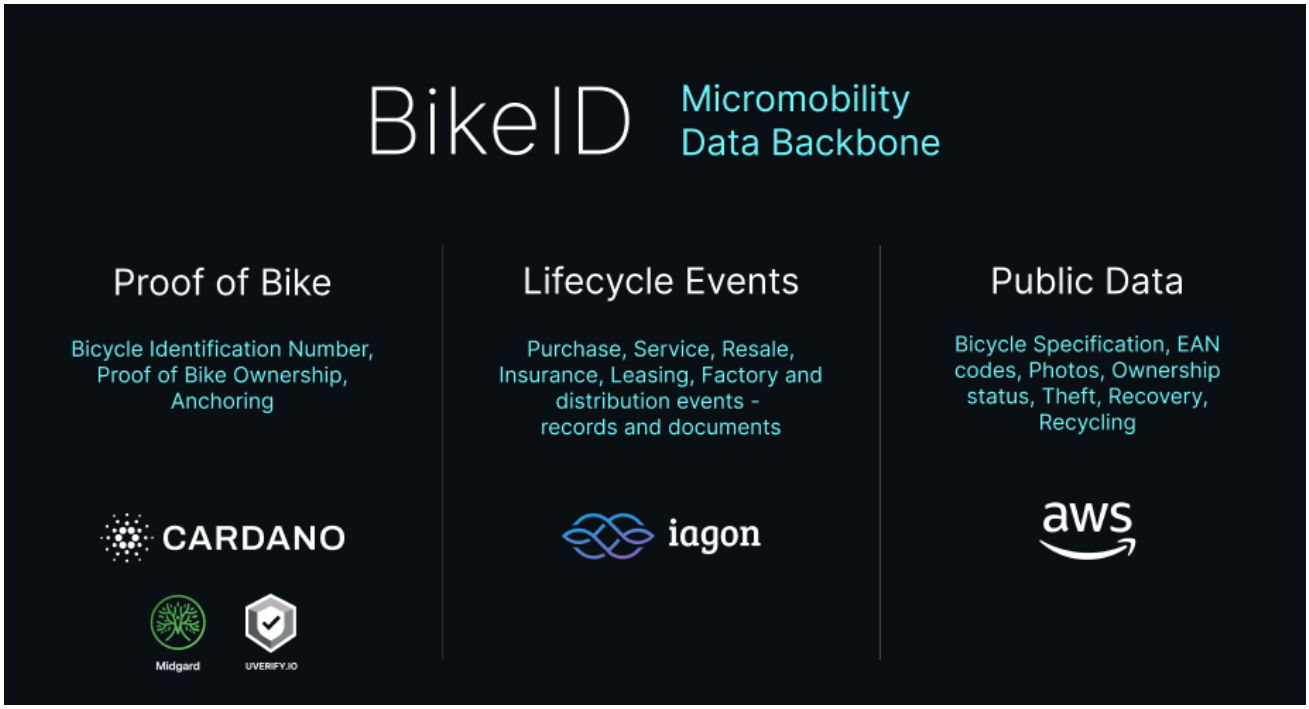
3.4 Scalability

In Real World Asset (RWA) tokenization, a common design pattern is to mint a unique on-chain token for every asset. While effective for high-value, low-volume assets such as real estate or art, this approach is impractical for **consumer-scale industries** like cycling, where tens of millions of bicycles change hands annually. High volumes of low-value assets require a more efficient model.

BikeID adopts a **sharded Merkle registry architecture** optimized for Cardano's EUTxO model:

- **Shard-Level Anchoring:** Instead of tokenizing each bicycle individually, groups of BINs are recorded in shard registries, each represented by a single UTXO.
- **Merkle Commitments:** Lifecycle changes update the shard's Merkle root, rather than creating or moving tokens.
- **Lightweight Proofs:** Verification of ownership or status is achieved through Merkle proofs against the latest shard root, allowing trustless validation at minimal cost.
- **Parallelization:** Independent shards enable high throughput and concurrency, ensuring the system can scale to **tens of millions of assets**.

This approach combines the benefits of RWA tokenization, **verifiable ownership, tradability, auditability**, with the efficiency required for consumer-grade adoption. By anchoring proofs of identity and ownership on Cardano while storing high-volume data off-chain, BikeID demonstrates how blockchain can support **everyday physical assets at global scale**, not just luxury or institutional RWAs.



4. Partner Roles

BikeID leverages a consortium of technology and industry partners, each playing a distinct role in the Micromobility Data Backbone:

4.1. Technology Partners

- **Cardano:** Provides the immutable Layer 1 infrastructure for registering BINs, anchoring Proof of Bike and Proof of Bike Ownership, and executing Plutus smart contracts.
- **Iagon:** Supplies decentralized storage for lifecycle data (service logs, warranties, insurance records), ensuring GDPR-compliant handling with cryptographic integrity proofs.
- **Midgard:** Offers a Cardano-compatible Layer 2 environment for high-frequency or cost-sensitive lifecycle events, improving scalability and affordability of large-scale adoption.
- **UTxO:** Simplifies UTXO workflows and enables OEMs and retailers to integrate BikeID registration and updates into their existing systems with minimal blockchain complexity.
- **uVerify:** Provides the verification and attestation layer through **custom digital certificates**. Each ownership transfer, lien, or recycling event is accompanied by a certificate issued by the responsible entity, ensuring trust and compliance across the ecosystem.

4.2. Users and Institutions

- **OEMs and Retailers:** Register bicycles at manufacturing or point of sale, embedding BINs into their distribution workflows and enabling downstream lifecycle services.
- **Insurers and Financial Institutions:** Use BIN-linked PoBO records and uVerify certificates to reduce fraud, support financing, and automate insurance claims.
- **Municipalities and Regulators:** Access public-facing BIN data (e.g., theft/recovery status, recycling certificates) to support policy goals, compliance monitoring, and sustainable mobility initiatives.
- **Industry Organizations (e.g., CIE, CONEBI):** Support adoption of BIN as an open, neutral industry standard, ensuring compatibility across manufacturers, promoting best practices, and aligning with EU sustainability frameworks such as the Digital Product Passport and Battery Passport.

5. Use Cases

1. **Ownership & Theft Protection:** Immutable PoB and PoBO records deter theft, block resale of stolen bikes, and aid recovery.
2. **Lifecycle Management:** Service logs and warranties tied to BIN increase resale value and enable recurring brand interactions.
3. **Retail & OEM Integration:** Registration at point of sale binds bikes to brand ecosystems, unlocking warranties, upgrades, and insurance packages.

4. **Insurance & Financing:** PoBO reduces fraud and enables micro-financing of e-bikes, usage-based insurance, and leasing.
5. **Sharing & Rentals:** Smart contracts manage deposits, usage time, and returns; P2P bike-sharing becomes trustless.
6. **Resale Market:** Buyers verify PoB/PoBO instantly, creating secure second-hand liquidity and improving trust.
7. **Circular Economy & Sustainability:** Verified service histories extend lifespans, align with EU Product/Battery Passport standards, and support ESG reporting.
8. **Cultural and Creative Extensions:** Collaborations with Loca and Arts Academy allow limited-edition BIN-linked bikes and NFTs for emerging artists.

6. Cardano Impact

BikeID is designed not only as an industry solution for cycling, but also as a strategic adoption driver for the Cardano ecosystem. By anchoring millions of physical assets and their lifecycle events on-chain, the project demonstrates Cardano's ability to operate at consumer scale in a way few blockchain projects have achieved.

6.1 Mass Adoption

- With over 20 million bicycles sold annually in Europe alone, BikeID has the potential to register millions of assets within the first years of deployment.
- Each bike generates dozens of lifecycle events (service, warranty, insurance, resale, recycling) leading to billions of verifiable on-chain transactions over time.
- This transaction density positions Cardano as the backbone for a global, high-volume, low-cost RWA ecosystem.

6.2 Showcase of Cardano's Strengths

- **Scalability:** Merkle registry architecture and Layer 2 extensions (Midgard) demonstrate how Cardano can handle mass-market RWAs without congestion.
- **Smart Contracts:** Plutus validators govern ownership, liens, and recycling processes, showing blockchain can automate complex, real-world business logic.
- **Cost Efficiency:** Cardano's low transaction fees make it viable for consumer-scale adoption, unlike high-fee L1 competitors.
- **Identity & Certificates:** uVerify's certificate framework demonstrates practical, DID-compatible identity management on Cardano, filling a critical market gap.

6.3 Ecosystem Activation

- Integrates Cardano-native infrastructure and partner protocols including:
    - **Iagon** for decentralized storage,
    - **Midgard** as a Cardano-compatible L2 for scalability,
    - **uVerify** for custom certificates and verification,

    - **UTxO** for workflow abstraction.
- By combining these components, BikeID activates multiple parts of the Cardano ecosystem, creating synergies and proving interoperability in a live, revenue-generating use case.

6.4 Cardano RWA Leadership

- BikeID positions Cardano as the leading blockchain for consumer-scale Real World Asset tokenization.
- While most RWA projects target institutional or high-value assets (real estate, carbon credits), BikeID demonstrates that blockchain can underpin everyday consumer goods at scale.
- This strengthens Cardano's narrative as the chain of choice for trust, identity, and sustainability in physical asset markets.

6.5 Social and Environmental Value

- **Theft Deterrence:** Immutable Proof of Bike and Proof of Ownership records make stolen bikes harder to resell, reducing incentive for theft.
- **Sustainability:** Verified service and recycling certificates extend bicycle lifespans, promote repair culture, and reduce waste.
- **Circular Economy:** Alignment with EU Digital Product Passport and Battery Passport frameworks ensures compliance with upcoming sustainability regulations.
- **Public Good:** Municipalities and regulators gain access to anonymized, verifiable data to improve urban mobility planning and ESG reporting.
- **Economic Disruption**: Adding €200+ in lifecycle value per bike through better resale, insurance, and services.
- **Industry Standards**: Influencing bodies like CONEBI (European Bicycle Industries) and CIE (Cycling Industries Europe) to adopt BIN as a global standard.

6.5 Sustainability Alignment

- **EU Green Deal:** supports modal shift to cycling by reducing theft, improving resale, and making bikes a more secure long-term investment.
- **Circular Economy:** verifiable service histories extend product lifespans and encourage repair over disposal.
- **EU Product and Battery Passports:** BIN records integrate seamlessly with mandated lifecycle reporting, ensuring compliance and traceability.
- **ESG Compliance:** OEMs and retailers can demonstrate measurable sustainability outcomes, including carbon footprint reduction and waste minimization.

7. Implementation Roadmap

Phase 1: Core Infrastructure

- Define BIN schema and generation algorithm (open source).
- Deploy initial Plutus contracts for **Proof of Bike (PoB)** anchoring.
- Pilot integration with OEM partners (limited production runs).
- Build registry UI + basic API endpoints.

Phase 2: Lifecycle Layer

- Implement **Proof of Bike Ownership (PoBO)** state machine.
- Integrate **uVerify certificates** for ownership transfers, liens, and recycling events.
- Deploy **lagon** for service logs and warranty data.
- Launch retail pilot with selected dealer networks.

Phase 3: Scaling & L2

- Integrate **Midgard L2** for high-frequency lifecycle events.
- Implement Merkle registry sharding for scalability.
- Develop APIs for insurers and financing institutions.
- Begin municipal/regulatory pilots (e.g., theft reporting, recycling certificates).

Phase 4: Ecosystem Rollout

- Large-scale OEM onboarding (integration at factory and point of sale).
- Insurance, leasing, and financing services live.
- Public-facing portals for resale verification and theft checks.
- Operational readiness for **millions of bikes registered**.

Future Roadmap

- **DeFi integrations:** Financing pools, insurance staking, secondary markets.
- **NFT authenticity certificates:** Limited-edition models, Loca Bikes art collaborations.
- **EU compliance:** Full alignment with Digital Product Passport and Battery Passport regulations.
- **Tokenized fleets:** Fractional bike ownership and shared revenue models for micromobility operators.

8. Governance & Sustainability

8.1 Open Standards

The **Bicycle Identification Number (BIN)** protocol is designed as an open, transparent standard. Any manufacturer, retailer, or ecosystem participant may implement the protocol without proprietary licensing. By adopting an open standard:

- Interoperability across brands and markets is guaranteed.
- Consumers are protected from vendor lock-in, ensuring continuity of records across the lifecycle of the asset.
- Industry associations (e.g., CIE-CONEBI) and regulators can reference a neutral, transparent specification rather than fragmented proprietary solutions.

8.2 Partnerships

BikeID's governance model is consortium-driven, involving a diverse set of stakeholders:

- **OEMs and Retailers:** responsible for embedding BINs at manufacturing or point of sale.
- **Insurers and Financiers:** benefit from verifiable ownership and lifecycle data to reduce fraud and underwriting risk.
- **Cities and Municipalities:** gain access to anonymized fleet and lifecycle insights, supporting mobility planning and sustainability policies.
- **Regulators:** oversee compliance with existing and emerging frameworks such as the EU Digital Product Passport.

Governance ensures that each stakeholder type retains an incentive to participate while collectively supporting the adoption of BIN as an industry-wide standard.

8.3 Business Model

The economic model is intentionally lightweight and transparent:

- **Registration fees:** BIN issuance is free of charge
- **RFID & NFC tag issuance:** typically borne by manufacturers or retailers.
- **Event fees:** lifecycle events such as ownership transfers, service updates, or leasing application incur a nominal charge (e.g., €0.25 per event). These fees generate recurring on-chain activity while remaining accessible to consumers.
- **BikeID Kits:** prepackaged NFC Tag + Proof of Ownership Card, sold in B2C model or in store
- **B2B APIs and Integration Services:** enterprises (insurers, marketplaces, governments) may subscribe to API access and analytics services for real-time BIN validation and lifecycle data.

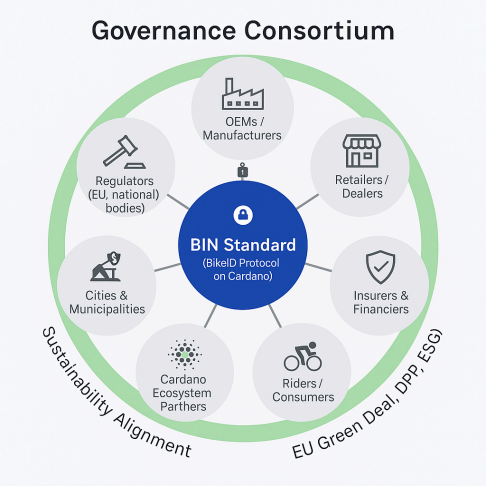
This combination balances affordability for consumers with sustainable revenue streams for long-term ecosystem maintenance. By linking economic value to sustainable practices, BikeID strengthens both industry profitability and environmental responsibility.

8.5 Governance Mechanisms

Future governance may evolve into a **multi-stakeholder consortium** responsible for:

- Maintaining the BIN standard.
- Certifying compliant implementations.
- Coordinating upgrades to ensure backward compatibility.
- Aligning with regulatory developments at the EU and global level.

This governance model ensures neutrality, prevents capture by any single party, and maintains trust across the ecosystem.



9. BikeID as a Real World Asset (RWA) on Cardano

BikeID exemplifies a practical RWA application on Cardano by tokenizing physical bicycles as digital assets, creating a bridge between the real world and blockchain. Unlike traditional RWAs focused on high-value items like real estate or commodities, BikeID targets everyday consumer goods, bicycles and turning them into verifiable, trackable assets.

9.1 Digital Representation via BIN

Each bike receives a unique 24-character Bicycle Identification Number (BIN), serving as its digital identity. This BIN creates a "digital twin" of the physical bike, with key data (e.g., ownership and specifications) anchored immutably on the Cardano blockchain through "Proof of Bike" and "Proof of Bike Ownership" records. This tokenization allows bikes to be represented as RWAs, enabling secure, on-chain verification without intermediaries.

9.2 RFID/NFC Integration

Tamper-proof, ultra-thin RFID/NFC tags are embedded into bike frames during manufacturing or applied at retail. These tags link the physical bike to its digital BIN, allowing users to scan for activation, ownership transfers, or theft reporting. This hybrid approach ensures the RWA is tied to a tangible asset, with scans triggering on-chain updates for real-time status changes (e.g., marking a bike as stolen).

9.3 Data Storage and Management

Static and critical data is stored on-chain for transparency and security. Dynamic elements, like service logs or ownership history, are handled off-chain in decentralized storage solutions like Iagon (a Cardano-based partner), reducing costs while maintaining blockchain anchors. This setup supports lifecycle management, including maintenance records, upgrades, and resale, adding value over the bike's lifespan (estimated at €200 per bike in additional revenue streams).

As an RWA, BikeID could onboard millions of bikes, generating billions of on-chain transactions and positioning Cardano as a leader in non-financial blockchain applications. It demonstrates how RWAs can solve everyday problems like asset fragmentation, boost industry efficiency, and promote sustainable tech (leveraging Cardano's PoS).