Enhanced Rock Weathering (ERW) Projects on Malama: Full Protocol & Technical Architecture Report

Protocol Compliance: Isometric Enhanced Weathering in Agriculture v1.1

Blockchain Infrastructure: Cardano (Native Tokens & DIDs)

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1. Executive Summary: The "Proof of Truth" Architecture

Malama Labs utilizes a decentralized verification stack to ensure that every carbon credit is backed by immutable, auditable proof. This system relies on three core pillars:

1. **Identity (DID) Layer:**
    - **Project Company:** Validated via KYB (Know Your Business). Issued a **Project DID**.
    - **Authorized Staff:** Validated via KYC. Issued **Staff DIDs** linked to the Project DID.
    - **Sensors (Machine Identity):** Critical hardware (scales, pH sensors, rain gauges) issued **Device DIDs** with embedded private keys for signing data at the source.
2. **Project Wallet:** A dedicated Cardano wallet that holds the project's assets.
    - **Liquid Carbon Tokens (LCT):** Minted upfront (based on AI Risk Score) upon Project Validation (Phase 1).
    - **Verified Carbon Tokens (VCT):** Minted ex-post (Phase 4). Represents **100%** of verified sequestration. *Note: LCTs are burned as VCTs are minted.*
3. **Source of Truth:** Every data point originates from either a **Validated Sensor** (Hardware Sign) or an **Authorized Human** (DID Sign).

Phase 1: Project Setup & Baseline (Pre-Operations)

Goal: Establish legality, safety, and the "zero state" before carbon removal begins.

1.1 Required Documents (Immutable Records)

All documents are hashed to IPFS; the Content ID (CID) is signed by the uploader's DID.

Document / Item	Source (Origin)	Metadata Requirements (JSON)	Verification Method

Project Design Document (PDD)	**DID:** Project Lead	doc_type: "PDD", version: "1.1", protocol: "Isometric-ERW-v1.1", total_projected_cdr: "1000 tCO2e"	**DID Signature:** Project Lead signs IPFS Hash.
Feedstock Acquisition Contract	**DID:** Legal Team	supplier_did: [DID], material_type: "Basalt", term_years: "1"	**Smart Contract:** On-chain agreement reference.
Affidavit of Waste / EC1	**DID:** Supplier	material_origin: "Quarry_Fines", economic_value: "0.00", exclusion_clause: "Waste_Input"	**DID Signature:** Supplier DID counter-signs.
Land Use / Right of Use	**DID:** Landowner	parcel_id: [ID], rights_assigned_to: [Project DID], duration: "5_Years"	**DID Signature:** Landowner DID counter-signs.
Social Risk Assessment	**DID:** 3rd Party Auditor	auditor_did: [DID], risk_score: "Low", mitigation_plan: "Traffic_Control_v1"	**Multi-Sig:** Project Lead + Auditor.
Environmental Risk Assessment	**DID:** Env. Consultant	soil_metal_risk: "Pass", water_risk: "Low", mitigation: "pH_Monitoring"	**DID Signature:** Consultant DID.

1.2 Sensor Deployments & Baseline Data

Sensor / Data Point	Source (Origin)	Metadata Requirements (JSON)	Verification Method
Soil Baseline Analysis	**Lab API (Oracle)**	baseline_ph: "5.8", base_saturation: "45%", cec: "12 meq/100g", lab_accreditation: "ISO 17025"	**Oracle Feed:** Direct data push from Lab LIMS.
Feedstock Characterization	**Lab API (Oracle)**	mineralogy: "Basalt", silicate_percent: "48%", heavy_metals: "Safe", cdr_potential: "0.3 tCO2/t"	**Oracle Feed:** Lab API.
Hydrologic Baseline	**DID:** Hydrologist	water_table_depth: "5m", drainage_class: "Well Drained", watershed_id: [ID]	**DID Signature:** Certified Hydrologist.

1.3 Events

- **Site Selection & Plot Designation:** GPS Polygons defining Control (2.5%), Treatment (2.5%), and Deployment (95%) areas established on-chain.
- **Feedstock Sampling:** Initial batch sampling for mineralogy confirmation.

1.4 Token Action: Adaptive Pre-Issuance

Goal: Determine the percentage of Projected Carbon Tokens to mint as Liquid Carbon Tokens (LCT).

- **The AI Risk Engine** analyzes the Phase 1 proofs to generate a **Confidence Score (0-100)**.
    - **Project Completeness (30%):** Are all contracts (Feedstock, Land Use) signed on-chain? Are plot polygons defined?
    - **Economic Feasibility (20%):** Is the feedstock a waste product (improving margins)? Is the transport distance <50 miles?
    - **Developer Reputation (25%):** Does the Project DID have a history of successful ERW deployments?

    - **Methodology Risk (25%):** ERW has medium complexity. Is the specific basalt mineralogy high-reactivity (lower risk) or low-reactivity (higher risk)?
- **Outcome:**
    - *Example:* **Score 85/100** -> Protocol mints **65%** of projected removal as LCTs to the Project Wallet.

Phase 2: Deployment & Application (The "Action")

Goal: Apply the rock dust and prove it is physically there.

2.1 Required Documents

Document / Item	Source (Origin)	Metadata Requirements (JSON)	Verification Method
Feedstock Weight Ticket (Source)	**Sensor:** Weighbridge	device_id: "Scale-001", weight_kg: "500000", load_id: "Load-A1"	**Hardware Sign:** Private key in sensor signs data.
Transport Manifest	**DID:** Logistics	carrier_did: [DID], start_time: [Unix], end_time: [Unix]	**Multi-Sig:** Carrier + Receiver.
Feedstock Weight Ticket (Field)	**Sensor:** Weighbridge	device_id: "Scale-Field-01", weight_kg: "500000", variance: "0.0%"	**Hardware Sign:** Private key in sensor signs data.
Variable Rate Map	**DID:** Agronomist	map_hash: [IPFS CID], target_rate: "10 t/acre", zoning: "pH_based"	**DID Signature:** Agronomist DID.

2.2 Sensor Deployments & Tracking

Sensor / Data Point	Source (Origin)	Metadata Requirements (JSON)	Verification Method
GPS Spreader Tracks	**Sensor:** Tractor IoT	coverage_polygon: [GeoJSON], speed: "5 mph", flow_rate: "High"	**Spatial Verification:** GPS tracks overlay on Field Boundary.
Spreader Load Cells	**Sensor:** Load Cell	start_weight: "10000 kg", end_weight: "500 kg", applied_mass: "9500 kg"	**Hardware Sign:** Signed data packet.
Fuel Consumption Log	**Sensor:** Telematics	fuel_liters: "150", distance_km: "80", vehicle_id: "Truck-01"	**Hardware Sign:** OBD-II Dongle signature.

2.3 Events

- **Transport:** Movement of rock from quarry to field (GPS tracked).
- **Application (Spreading):** Physical spreading of rock dust on the Deployment Plot.
- **Post-Spread Verification (Day 0):** Soil sampling to detect "Immobile Tracer" (e.g., Titanium) spike, confirming application rate.

Phase 3: Operations & Monitoring (The "Evidence")

Goal: Prove weathering is happening via chemical and climatic data.

3.1 Required Documents

Document / Item	Source (Origin)	Metadata Requirements (JSON)	Verification Method

Soil Analysis Report (Monitoring)	**Lab API (Oracle)**	current_ph: "6.2", cation_depletion: "Detected", batch_id: "Monitor-01"	**Oracle Feed:** Lab API.
Porewater Analysis Report	**Lab API (Oracle)**	alkalinity: "Increased", dic: "0.05 mol/kg", heavy_metals: "Safe"	**Oracle Feed:** Lab API.
Biomass Yield Record	**DID:** Farm Operator	crop_type: "Alfalfa", yield_tonnes: "50", harvest_date: [Unix]	**DID Signature:** Farm Operator DID.

3.2 Sensor Deployments & Tracking

Sensor / Data Point	Source (Origin)	Metadata Requirements (JSON)	Verification Method
Rainfall / Weather Station	**Sensor:** IoT Station	precip_mm: "12", soil_temp_c: "15", soil_moisture: "25%"	**Hardware Sign:** Signed data packet (Daily).
Lysimeter / Porewater Sampler	**DID:** Field Tech	sample_id: "Lys-01", volume_ml: "500", ph_field: "6.5"	**DID Signature:** Technician logs sample collection.
Satellite NDVI Stream	**API (Sentinel-2)**	ndvi_mean: "0.6", health_status: "Good", change_vs_control: "+2%"	**Oracle Feed:** Automated API pull.

3.3 Events

- **Climatic Trigger:** Rain event recorded (initiates weathering reaction models).
- **Quarterly Sampling:** Soil and Porewater samples collected from Control and Treatment plots.

- **Harvest:** Biomass removal recorded (to deduct cations taken up by plants).

Phase 4: Quantification & Verification (The "Credit")

Goal: Calculate the net impact and mint the asset.

Token Action: Smart Contract Burns LCTs and Mints VCTs based on Final Net Calculation.

4.1 Required Documents

Document / Item	Source (Origin)	Metadata Requirements (JSON)	Verification Method
LCA Report	**DID:** System Auto-Gen	total_emissions: "2.5 tCO2e", quarry_emissions: "1.0", transport_emissions: "1.0", spreading_emissions: "0.5"	**Algorithmic:** Calculated from aggregated sensor data.
Net CDR Calculation Sheet	**DID:** System Auto-Gen	gross_removal: "156.9 tCO2e", net_removal: "154.5 tCO2e", buffer_pool: "5%"	**Algorithmic:** Isometric Formula (Eq 1 & 3).
Verification Report	**DID:** VVB (Verifier)	verification_standard: "Isometric-ERW-v1.1", audit_result: "Pass", verifier_did: [DID]	**DID Signature:** VVB signs final report.
Credit Issuance Statement	**Registry**	token_id: [Asset ID], serial_numbers: [Range], mint_date: [Unix]	**On-Chain:** Transaction Hash.

4.2 Events

- **Data Aggregation:** System compiles all signed proofs (Mineralogy, Spreading GPS, Weather Data, Lab Results) into a Verification Pack.

- **Third-Party Audit:** VVB reviews proofs and visits Control/Treatment plots.
- **Credit Issuance:** Registry executes minting policy.

Master Timeline Visualization

Phase	Timeframe	Key Milestone
1. Setup	Months 1-2	**Validation:** PDD Approval, Feedstock Analysis. **Token:** Mint LCT (Pre-Issue %).
2. Deployment	Day 0	**Activity:** Spreading, Weight Verification, Tracer Confirmation.
3. Operations	Year 1+	**Monitoring:** Rainfall, Soil/Water Sampling, Weathering Reaction.
4. Credit	Annual	**Verification:** Audit complete. **Token:** Burn LCT / Mint VCT (Net Realized).