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ColdBox — Battery-Free Cold Storage for Smallholder Markets

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Proposed Solution

Problem: Nigeria loses ₦3.5–5 trillion of horticultural produce annually; up to 48% of tomatoes and peppers spoil before sale because grid power is unreliable, lithium-battery solar fridges are unaffordable (₦500K–1.5M), and ethylene continues to ripen produce even when cooling fails.

ColdBox is a battery-free, three-layer cold-storage unit engineered for the off-grid Nigerian market trader:

• Thermal layer — phase-change material (salt-hydrate, Tm ≈ 8–12 °C) holds chamber temperature for 48–72 hrs without power.

• Chemical layer — $KMnO_4$ ethylene scrubber + silica gel + KOH-zeolite trap suspends ripening even when cooling lapses (“Eco-Survival Mode”).

• Energy layer — CarbonVolt supercapacitor module (activated carbon from palm-kernel-shell waste) buffers compressor inrush, enabling a 50–60% smaller solar array and eliminating the imported Li-ion battery.

Outcome: 10–14 days of usable shelf life (vs. 2 days unrefrigerated), at ~₦85K–120K per unit, locally assembled with a clear path to domestic component sourcing.

Economic Feasibility & Business Model

Unit economics (per smallholder trader):

• System cost: ₦85K–120K (vs ₦500K–1.5M for solar fridge + Li-ion battery).
• Daily spoilage avoided: ₦16K–36K based on FAO/OTACCWA 2023 trader survey.
• Simple payback: 5–8 days at median daily turnover.
• Hardware lifespan: 15–20 yrs — no battery to replace.
• Cartridge service revenue: ₦1,500–3,500/month (recurring).

Revenue streams:

(1) Unit sale + USSD micro-finance (₦5K deposit + ₦5K/month over 18 mo) — captures price-sensitive traders.
(2) Cartridge subscription — locally assembled, swap-and-pay; gross margin ~55%.
(3) Shared “Hub” rental in market clusters — pay-per-day USSD access for the lowest-income tier.

Margins: unit gross margin ~35% at scale; cartridge gross margin ~55%. Break-even ≈ 400 units deployed.

Technical Design

Insulated chamber: 60 L food-grade liner inside PU-foam-lined sheet-metal shell ($U \leq 0.6$ W/m²K). Cooled by a 12 V DC compressor driven by a right-sized 100 W solar PV panel + CarbonVolt supercapacitor module.

Energy buffering: CarbonVolt cells use KOH-activated carbon electrodes derived from carbonised palm-kernel shells (aqueous electrolyte). The supercapacitor absorbs compressor surge currents at start-up, extending compressor life and removing the need for a lead-acid or Li-ion battery bank.

Thermal storage: salt-hydrate eutectic ($CaCl_2$-based blend with nucleating agent) tuned to Tm ≈ 8–12 °C — matched to the chilling-injury-safe range for tomatoes and peppers. Stored in 20 kg sealed HDPE pouches around the chamber walls.

Ethylene control: PVC cartridge holding three stages — silica-gel desiccant → $KMnO_4$ on inert pellets (oxidises C_2H_4 to CO_2 + H_2O) → KOH-zeolite trap (captures MnO_2 and trace by-products). Swappable, designed for ~30-day field service life.

Telemetry: ESP32 + DHT22 (T, RH) + MQ-135 (gas) + SIM800L for SMS alerts on temperature excursion or cartridge exhaustion. A Python digital-twin simulates 72 h of operation in < 5 s, used for design validation and field-data calibration.

Timeline for Prototype / Trial

Phase 1 — Months 1–3: Lab Prototype
PCM formulation finalised + freeze-thaw cycle testing (UNILAG ChemEng lab); $KMnO_4$ cartridge sized for 30-day life; CarbonVolt cell fabrication and characterisation; digital-twin model validated against bench data.

Phase 2 — Months 4–6: Field Prototype
Build 5 instrumented units; deploy to traders at Mile-12, Mushin, and Oyingbo markets in Lagos for a 60-day field trial. Track produce weight loss, spoilage rate, internal temperature profile, and trader satisfaction via ESP32 telemetry.

Phase 3 — Months 7–9: Pilot Deployment
Scale to 25 units across 3 Lagos markets; integrate USSD payments with a partner micro-finance institution; trial the Hub rental model in one market cluster; file provisional IP through NOTAP.

Phase 4 — Months 10–12: Scale-up
Train 3 fabrication workshops (Lagos, Ibadan, Onitsha); production run of 100 units; cross-state expansion to Ibadan and Abeokuta; finalise cartridge-supply licensing model.

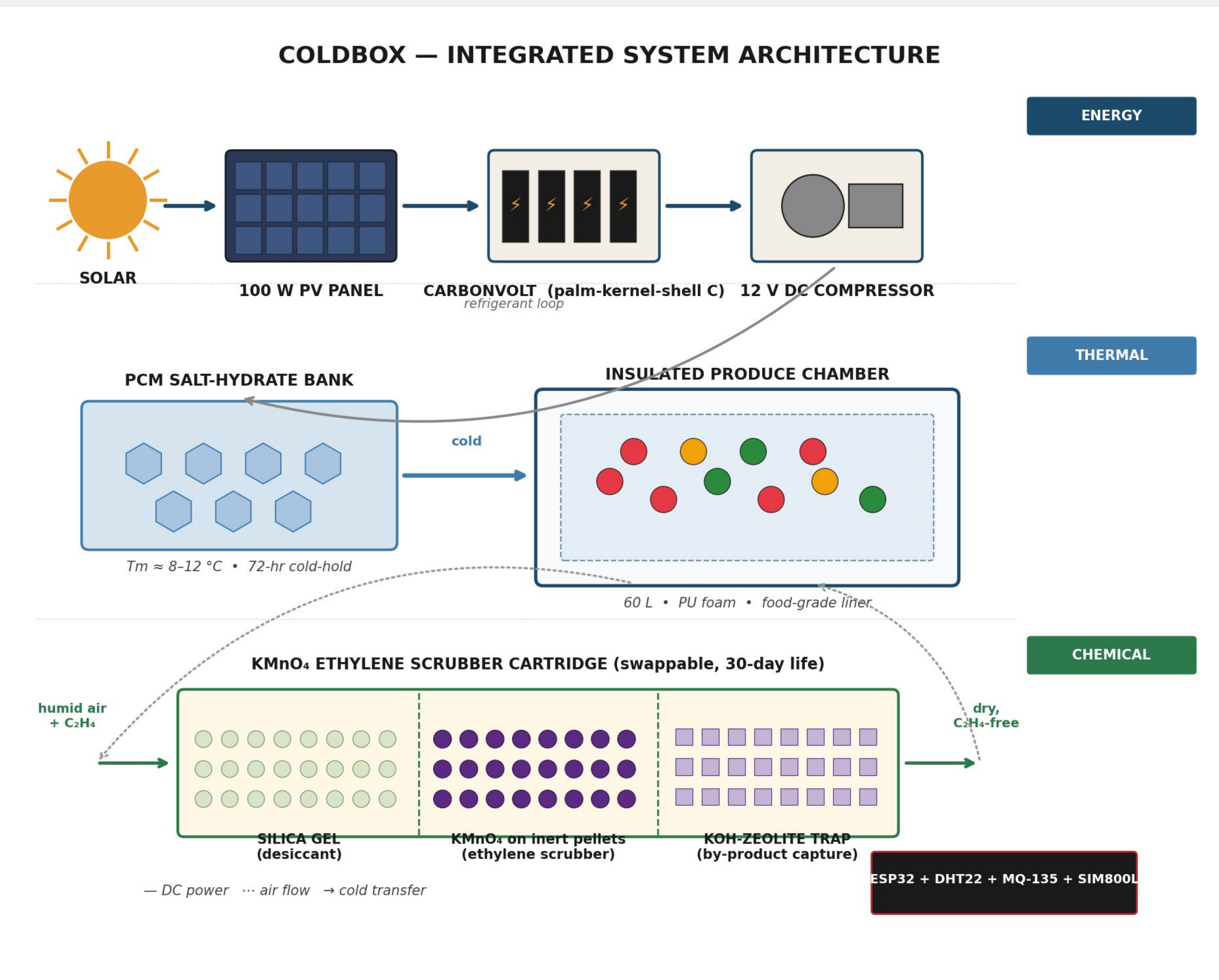

Fig. 1: ColdBox system schematic — three-layer architecture (Energy | Thermal | Chemical) integrating solar PV, palm-kernel-shell supercapacitor, salt-hydrate PCM cold store, $KMnO_4$ ethylene scrubber, and ESP32 telemetry.

Budget & Target User / Market / Scale

Budget (₦M): Prototyping 4 | Field trial 6 | Pilot 15 | Workshop fit-out 8 | Working capital 5 | TOTAL: ₦38M.

Primary user: smallholder tomato/pepper traders (₦5K–40K daily turnover) in major urban wet markets — Lagos, Ibadan, Onitsha, Kano. 70%+ are women.

Market size: ~2.4M traders nationally handle perishable horticulture; Lagos-only SAM ≈ 180,000 traders. Initial SOM (Years 1–2): 500 units across 5 Lagos markets; Year 3 target: 3,000 units across 6 states with pan-African pilots in Ghana and Kenya.

Impact: each 100-unit deployment saves ~₦1.6–3.6 Bn of produce per year and creates ~16–25 local fabrication jobs (≥50% women).

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