

Last Light on Maui: Elite Enclaves in a Radioactive World (Post-Cataclysm)

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This paper imagines Maui after the unthinkable: a cataclysm that leaves the island's towns silent and the trade winds carrying more ash than salt. In this setting, "community" no longer constrains design. What follows is a technical anthropology of the few who planned, sealed, and survived—owners and staff inside hardened compounds cut into the leeward slopes and littoral lava benches. Their objective is not stewardship or parity; it is continuity of their own bloodlines, assets, and tastes for as long as consumables, membranes, and discipline hold. We describe how such enclaves could operate as closed micro-states: pressurized galleries and garden courts under sacrificial glazing; RO plants that drink the sea and exhale brine into unmourned coves; rack-grown greens and recirculating fish; libraries, theaters, and clinics maintained like engines; and a robotized exterior that is not a commons but an annulus of extraction and warning. With no public to answer to, the constraints shift: uptime over approval, secrecy over transparency, and a politics of succession measured in access keys, not ballots. We map the stack—air, water, power, food, waste, security, labor—alongside the inevitable failure modes and endgames when filters clog, heirs quarrel, and the island stops giving more than it takes.

Keywords: radioactive world, Maui, elite bunker, post-cataclysm, positive-pressure habitat, seawater RO, indoor agriculture, aquaculture, sealed logistics, robotic perimeter, succession governance, cultural vault, security doctrine, membrane fouling, filter scarcity, brine disposal, failure cascades, endgame planning.

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Outline

1. **Geography After People**

Wind and fallout patterns over empty Lahaina and Kīhei; safe elevations; coves for intakes and covert outfalls; why leeward benches and Haleakalā skirts become the last addresses.

2. **Tomb Architecture, Lived**

Cut-and-cover galleries, ribbed vaults, and light courts under laminated sacrificial glass; pressure zoning that treats each wing as a ship compartment; noise, smell, and light engineered to feel like weather.

3. **Air: The Only Luxury That Matters**

H14 banks, carbon beds, and prefilter ladders; overpressure doctrine; intake mounds disguised as dunes; filter rationing curves and the calculus of shutting wings to save media.

4. **Water: Sea to Cell**

Redundant seawater RO trains with IX polish; brine discharge into unpeopled embayments; color-coded potable/gray/black loops; corrosion and biofouling as the clock everyone hears.

5. **Power: Sun, Salt, and Silence**

PV canopies in bermed courtyards; baffled micro-wind; underground batteries with hydrogen detection; biodiesel and green H₂ as grace-notes; acoustic discipline as security.

6. **Food Without Fields**

Tiered hydroponics (leafy/fruitlet), mushroom racks, insect protein, closed-loop aquaculture; recipe cycles that trade palate variety for membrane life; legacy pantry management as a treasury function.

7. **Waste: Nothing Leaves Dirty**

Blackwater bioreactors, graywater polishing, solids to shielded drums; ash, sludge, and filter cakes logged but not litigated; when the drum yard becomes the moral horizon.

8. **Robotic Exterior**

HEPA sweepers on intake corridors, gutter crawlers to keep roofs from kindling, utility manipulators for valves and clamps, drone sentries that map heat and dose—an outdoor world reduced to perimeter, pathway, quarry.

9. Labor, Class, and Containment

Staff bunkers downstream of the main air tree; biometric access and work-credit ledgers; NDAs become constitutions; rotation, reward, and exile policies when the island offers nowhere to go.

10. Security Doctrine in an Empty Country

Deny–detect–deter without witnesses: RF fencing, anti-drone umbrellas, intrusion beacons, decoy intakes; incident playbooks that privilege secrecy and uptime over investigation.

11. Clinic, Apothecary, and Mortuary

What medicine looks like without resupply: anesthesia rationing, antibiotic stewardship, improvised dialysis, palliative protocols; the quiet logistics of death and remembrance underground.

12. Culture, Time, and Sanity

Libraries, instruments, theaters, and gyms treated like rotating crops; circadian lighting and ritual calendars; the danger of boredom as a systems risk; etiquette for silence and celebration.

13. Governance of the Few

Trusts as governments; key ceremonies, quorum masks, and succession drills; adjudication when the judge and the owner share a table; mutiny scenarios framed as maintenance disputes.

14. Procurement Without Markets

Cannibalization trees for robots, membranes, and vehicles; the sacrificial inventory (what gets burned to keep the rest alive); craft reskilling: machinist, brewer, glasser, medic.

15. Failure Cascades & Triage

From membrane fouling to water rationing to air compromise; from battery fault to blackout to food die-off; decision trees that shutter wings, cull programs, and redraw the social contract.

16. Endgames

Re-emergence when dose finally drifts down; diaspora by sea with sealed cargo; trading with distant enclaves by drone; or the archival end: sealing the vaults and writing to the future.

17. Appendix: The Clock Inventory

What actually governs survivability horizons: filters by square meter, RO pressure vessels, spare bearings, lithium cells, antibiotics, anesthetics, seed stock, and fiction.

References

1) Geography After People

1.1 Wind & fallout vectors over empty Lahaina and Kīhei

With no traffic or landscaping crews to keep surfaces moist, **trade-wind resuspension** becomes the island's metronome. The prevailing **NE trades** accelerate through the Pailolo and 'Alenuihāhā channels, wrap around West Maui, and rake **Lāhainā–Olowalu–Mā'alaea–Kīhei** from **NNE→SSW**. Expect a daily **upslope thermal pump** (mid-morning) that lifts fines toward benches, then a **downslope drain** after dusk that pushes dust back to the coast. Intermittent **Kona winds** (southerlies) reverse this, driving plume and ash directly into leeward coves and across the Central Valley. In practical terms:

- **Stable dirty corridors:** Honoapi'ilani Hwy frontage, Mā'alaea wind gap, North Kīhei Road flats—high PM and radionuclide re-loft.
- **Cleaner lee pockets (conditional):** wind shadows behind lava promontories and reef rims—useful for intakes but vulnerable during Kona events.
- **Valley amplifiers:** gulches (Kahoma, Kaua'ula, Ukumehame, Waipuilani) behave like bellows—avoid their fans for air intakes.

Rule: design for trades, defend against Konas. Shield intakes from both headings with baffles and sacrificial prefilters; schedule exterior robot work (sweeping, washing) during night downslope lulls.

1.2 Safe elevations: water, waves, and dust

Flood lines and dust lines are different maps. You need to clear both.

- **Tsunami/surge standoff:** site primary penetrations $\geq 30\text{--}40\text{ m ASL}$ *and* behind natural berms; place floodable garages below, with sacrificial doors.
- **Sea-level & storm creep:** assume +2–3 m baseline shift over decades; never site critical pumps below **+8 m ASL**.
- **Dust minimums:** at trades, PM and salt plume thin above **60–120 m ASL** on leeward slopes; higher helps but adds pumping head for seawater RO.
- **Gulch setbacks:** keep $\geq 200\text{ m}$ horizontal from any active drainage fan to dodge debris flows and midnight katabatics laden with fines.
- **Wildfire margins:** clear fuels $\geq 60\text{ m}$ downwind; maintain gravel fire roads as robot aisles on the contour.

Working band for “last addresses”: 60–180 m ASL on leeward benches and the **Kula/“Ulupalakua skirts**, with controlled access to a protected shoreline pump house.

1.3 Coves for seawater intakes & covert outfalls

In a dead island, optics don’t matter—hydraulics does. You still want **quiet coves** that deliver clean intake water and swallow brine without back-eddy.

Intakes (targets):

- **Depth: 10–20 m** (below surface scum, above high-energy bottom scour).
- **Velocity at screen: < 0.15 m/s** (biofouling control, low entrainment).
- **Geometry:** buried **cobble filter galleries** or wedge-wire laterals under sand lens; shore side vault with backflush manifold.
- **Siting:** lee of headlands (e.g., south of Olowalu points; La Perouse lava benches) with **dual headings** to hedge Konas.

Brine outfalls (targets):

- **Dilution: $\geq 100:1$** within **100 m** of diffuser at mid-tide.
 - **Placement:** outside reef flats into swift longshore; multiport diffusers at **+2 to +5 m** off bottom to avoid pooling in potholes.
 - **Camouflage:** route with the intake trench; use natural ledges to break jet noise (acoustic discipline = security).
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1.4 Ground truth: benches, basalts, and anchors

Leeward Maui gives you **competent basalt and lithified reef benches**—ideal for **cut-and-cover galleries** and **anchored intake vaults** if you respect joints and weathered caps.

- **Foundations:** key through saprolite to sound rock; drain mats behind all retaining walls to avoid uplift in Kona rain.
- **Seismic slips:** flexible couplers on intake risers; expansion joints every **10–15 m** in gallery ribs; pipe saddles with PTFE shoes.
- **Anchorage:** stainless or FRP anchors in chloride zones; cathodic protection on steel near splash.

1.5 Why leeward benches & Haleakalā skirts are the last addresses

- **Energy:** high insolation, reliable night cooling; wind micro-siting for baffled micro-turbines without salt blast.
 - **Hydraulics:** short, defensible runs to seawater; elevation that trades lower dust for manageable pump head.
 - **Defensibility:** few approach corridors; clean geofences; natural berms for sound and light discipline.
 - **Maintenance radius:** 15–25 min robot runs to pump houses and roof arrays; garages can sit mid-slope with downhill wash drains.
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1.6 Siting heuristics (hard numbers you can build to)

Air intakes:

place_on_leeward_backside_of_local_berm = true

crest_offset $\geq$ 8 m horizontal

intake_axis_angle_to_prevaling_trades = 120–150°

prefilter_area $\geq$ 10× HEPA face area

roofline_salt_spray_index $\leq$ threshold

Elevation & offsets:

elevation_ASRL = 60–180 m

tsunami_surge_clearance $\geq$ 30 m + berm

gulch_setback $\geq$ 200 m

wildfire_fuelbreak $\geq$ 60 m downwind

Seawater plant:

intake_depth = 10–20 m

screen_velocity $\leq$ 0.15 m/s

outfall_dilution $\geq 100:1$ @100 m

pump_head_total $\leq 40\text{--}60$ m (incl. losses)

Access & robotics:

approach_grade $\leq 12\%$

turning_radius ≥ 6 m (UGV+trailer)

wash_pad_slope 1–2% to sump (no crossfall)

1.7 Candidate micro-zones (illustrative)

- **Olowalu–Ukumehame Benches (W. Maui)**
Pros: reef-sheltered coves for intakes, rock benches for vaults, multiple lee pockets.
Cons: gulch fans; Kona reversals push ash inland; wildfire lanes along leeward slopes.
Fit: bunker galleries at **80–140 m ASL** with dual-heading intakes south of points.
- **Mā‘alaea Wind Gap & North Kīhei Flats**
Pros: relentless wind for dispersion; easy service corridors.
Cons: extreme dust; salt spray; shallow reef—tricky intakes.
Fit: only as **pump trunk corridor** and logistics pad; not for air intakes.
- **Kīhei–‘Āhihi–La Perouse Lava Benches (S. Maui)**
Pros: young lava ledges = anchor heaven; clear intake/outfall geometry; fewer gulches.
Cons: Kona exposure; salt blast; fragile lava tubes.
Fit: pump houses on benches; compounds up-slope at **90–160 m** with deep baffles.
- **Kula / ‘Ulupalakua Skirts (E. leeward Haleakalā)**
Pros: cooler air, reduced salt; strong solar; fewer wildfire flash corridors with cleared belts.
Cons: longer seawater lifts; fog/condensation on Kona shifts.
Fit: primary living galleries; seawater via armored utility canyon.

1.8 Design cues for an empty island

- **Orient everything for trades;** design *defeats* for Konas.
- **Treat gulches as lungs.** Never site intakes or airlocks within their breath.

- **Hide hydraulics in geology.** Filter galleries and outfalls belong under cobble and ledge, not as pipes in the surf.
- **Live in the band.** 60–180 m ASL is the survivability sweet spot: above surge and salt, below the pump curve cliff.
- **Map time, not just space.** Your cleanest air is 02:00–06:00 downslope; your dirtiest hour is the Kona gust you didn't expect. Schedule robots—and people—accordingly.

Bottom line: On post-cataclysm Maui, the “last addresses” are neither beachfront nor mountaintop but **mid-slope vaults** with quiet coves on a short leash. Get the wind and water wrong and nothing else matters; get them right and the island can still keep a few lungs breathing for a very long time.

2) Tomb Architecture, Lived

2.1 Structural typologies: cut-and-cover galleries, ribs, and frames

- **Primary form: Cut-and-cover galleries** driven into leeward benches, 6–8 m clear width, 3.2–4.0 m clear height. Excavation to competent basalt; gallery crown with **ribbed vaults** (reinforced shotcrete over rebar ribs @ 1.2 m centers) or precast arches with shear keys.
- **Liners:** triple layer—(i) waterproofing membrane with drainage mat, (ii) fiber-reinforced shotcrete liner (75–100 mm), (iii) service face (painted GRC panels on hat channels).
- **Floor:** floating slab on capillary break; under-slab drains to monitored sump; vibration-isolated plinths for loud equipment.
- **Seismic detailing:** expansion joints every 10–15 m with compressible waterstops; ductile links at door frames; flexible couplers on all services.

2.2 Pressure zoning: ship-compartment doctrine

- **Tree topology:** one **main air spine** (mechanicals) feeding **wings** (residential, clinic, kitchen, culture) via **pressure breaks**.
- **Z-levels (relative to ambient):**
 - **+35–50 Pa:** clinic, pharmacy, nursery.
 - **+25–35 Pa:** residences, classrooms, server room.
 - **+10–20 Pa:** kitchens, laundry, workshops.
 - **0 to –10 Pa:** waste prep, goods airlock vestibules (toward dirty side).

- **Compartmentation:** fire/smoke/pressure doors at each wing (motorized, fail-shut with manual dog). Transfer grilles with backdraft dampers; **air bridges** (HEPA-filtered cross-ties) to keep wings livable if the spine is offline.
- **Rules:** nothing crosses from lower to higher pressure without **wash, wipe, and count**; carts and totes have “directionality.”
- **Drills:** monthly “wing-isolation” where doors hard-shut; verify each wing’s **independent O₂/CO₂ control** and 12–24 h thermal buffer.

2.3 Light courts & sacrificial glazing

- **Light courts:** 4×8 m to 6×12 m wells that pierce to grade, lined with white GRC; tops capped by **laminated sacrificial glass** (multi-ply, replaceable outer sacrificial pane) beneath a low-profile bermed skylight hood.
- **Films & wash:** outer film strips peel and replace quarterly; **RO mist squeegee bots** keep deposition low; drain channels route washwater to sump.
- **Blast & debris:** steel mullions with yield links; laminated units sized for Class-III projectile resistance; **stone catchers**/screens above glass to intercept gravel in high winds.
- **Green cores:** planters with inert media; drip emitters; airflow drawn *down* into courts to keep dust out and deliver coolth at night.
- **Night mode:** blackout baffles if exterior glow is a signature risk; interior “sky engines” (see 2.6) take over.

2.4 Noise engineering: make machines disappear

- **Targets:** < 35 dBA sleeping, < 40 dBA library/class, < 45 dBA galley; mechanicals < 55 dBA at doors.
- **Measures:** resilient mounts, double-stud walls, baffled return plenums, labyrinth intakes; **quiet hours** schedule for pumps/RO backwashes.
- **Sound masking:** broadband “trade-wind” profiles in corridors at 28–32 dBA to hide hums and footfall.
- **Spatial tricks:** ribbed vaults break flutter echoes; soft furnishings at first reflection points; floor transitions for footfall control (rubber to wood to stone).

2.5 Smell discipline: olfactory zoning as morale

- **Air paths:** cooking and lab smells never leak “upstream.” Kitchens are lower-pressure than living rooms; flues have **activated carbon + HEPA**.

- **Positive scents:** herb walls near returns (mint, basil), micro-dosed by RO misters; **strict bans** on aerosolized cleaners.
- **Materials:** zero-VOC finishes; inert sealants; odor-neutral epoxies in wet rooms.
- **Monitoring:** VOC sensors in returns; threshold alarms drive **purge cycles** (high-flow RO mist + exhaust to dirty stack).

2.6 Light & time: simulating weather and circadian cues

- **Sky engines:** ceiling coffers with high-CRI LED arrays (6500 K dawn, 4000 K day, 2700 K dusk) and **dynamic gobo** projectors for slow cloud drift (8–20 min cycles).
- **Weather library:** presets—Trade-Wind Noon (bright, high contrast), Kona Overcast (flat, low contrast), After-Rain (cooler white, specular highlights).
- **Circadian program:** 24 h schedule per wing; **blue-reduced** evening; night-light at floor level (amber).
- **Health hooks:** SAD-risk residents get personalized **light doses** in reading niches; clinic can deliver targeted high-lux therapy.

2.7 Habitation program: a city under one roof

- **Residential runs:** 2.8–3.2 m wide galleries with room doors opposite pocket lounges; every fourth bay opens to a light court.
- **Galley & mess:** staged like a ship—prep → cook → plate → pass-through; **dish airlock** to scullery; olfactory trap curtains.
- **Clinic block:** treatment rooms with **anesthesia scavenging**, isolation room with independent AHU, dental chair on vibration slab, small OR with laminar canopy.
- **Culture & work:** library/theater with retractable risers; rehearsal room; maker bench (clean craft only); telepresence bays.
- **Wet core:** laundry, showers, hydroponic feed mix, RO lab, all on drain grid; floor falls to trench with clean-out ports.
- **Wayfinding:** color + iconography (trade-wind blues for clean spines, lava umbers for service runs); tactile floor ribs at pressure doors.

2.8 Life-support logistics: replaceable skin, inspectable core

- **Replaceable layers:** outer film on skylights; interior wall panels that unclip to reveal services; **sacrificial baseboards** catching drips and scuffs.

- **Inspection cadences:** endoscope ports at every 6 m for void checks; thermal scans quarterly for moisture behind liners.
- **Leaks & spills:** zoned drains with **p-traps + test tees**; dye-testing annually; “blue-water” drill for RO leaks (UV dye in test loops).
- **Fire safety:** clean-agent (FK-5-1-12) in server/electrical; water mist in kitchens; **compartment burn-through time ≥ 60 min.**

2.9 Air hardware: filters, ducting, and count points

- **Intakes:** berm-hidden snorkels; MERV-13 prefilters (sacrificial) → H14 HEPA banks → carbon bed; **ΔP sensors** across each stage.
- **Ducts:** lined steel with gasketed flanges; **test taps** every wing; color-coded—blue (supply), gray (return), purple (purge).
- **Service:** cassettes on slide rails; bag-in/bag-out ports; barcode every swap; portal gamma count on removals.
- **Emergency:** **smoke purge** mode reverses selected returns to dirty stacks; **comfort purge** clears a wing in ≤ 10 min at 10–12 ACH.

2.10 Operations: schedules, drills, heuristics

- **Daily:** filter ΔP sweep; sump levels; VOC/dust dashboards; light program tick.
- **Weekly:** door dog tests; pressure setpoint validation; odor audit walk.
- **Monthly:** wing-isolation drill (15 min goal to green); sky-engine calibration; acoustic check (pink-noise sweep).
- **Quarterly:** light-court film replacement check; thermal moisture scan; fire-damper cycle.
- **Heuristics:**
 - *If you can hear a pump, it's in the wrong room.*
 - *If you can smell dinner in a bedroom, a door or pressure is wrong.*
 - *If you see glare, the sky engine is mis-aimed.*
 - *If ΔP is flat for days, a sensor or a story is broken.*

2.11 Numbers to design by (quick table)

Element	Target	Notes
Gallery clear width/height	6–8 m / 3.2–4.0 m	Allows beds + carts + refuges
Overpressure (residential)	+25–35 Pa	Doors still operable
ACH (occupied / purge)	4–6 / 10–12	Energy vs comfort balance
Noise (sleep/lib/galley)	<35 / <40 / <45 dBA At 1.5 m, A-weighted	
Light court glazing	≥34 mm laminated	Outer sacrificial pane
Light levels (task/ambient)	500 / 200–300 lux	CRI ≥ 90
Odor/VOC threshold	TVOC < 500 ppb	CO ₂ < 900 ppm
Pressure door close	≤ 5 s to latch	Fail-shut, manual dog
Wing thermal drift (islanded)	≤ 1.5 °C/12 h	With fans only

2.12 Lived texture: why it doesn't feel like a bunker

- **Edges that breathe:** light courts pull air and sound like weather—sub-audible fans modulate to mimic gusts.
- **Material honesty:** stone at touch zones, wood at handrails, fabrics where ears rest; gloss only where cleaning demands it.
- **Rituals:** dawn “sky” in the gallery, midday herb wall mist, evening acoustic scene change. Habit is the thermostat of morale.

Bottom line: A survivable compound isn't just sealed; it's **pressurized, compartmented, and dramaturged**—a machine for living that hides its machinery. Get pressure, light, sound, and smell right and people can inhabit vaults for years without the rooms turning on them.

3) Air: The Only Luxury That Matters

3.1 Filtration stack: H14 banks, carbon beds, prefilter ladders

Goal: keep respirable dust and volatile byproducts out while minimizing filter burn-rate.

Stack order (dirty → clean):

1. **Inlet hood / bug screen** (washable) under a bermed **intake mound** (3.5–5 m dia, 1.2–1.8 m high).
2. **Prefilter ladder** (sacrificial): *G4* → *MERV 11* → *MERV 13* in parallel trays.
3. **Final HEPA bank (H14)**: ≥99.995% @ 0.3 μm, gasketed cassettes on slide rails; ΔP taps per row.
4. **Carbon bed** (post-HEPA): 25–40 cm GAC/impregnated mix in modular drawers; bypass-proof plenums.
5. **Polish/UV-C (optional)**: only for odor/bioburden management inside, never relied on outdoors.

Design hints:

- Face velocity ≤ **1.8 m/s** at prefilters, ≤ **0.45–0.6 m/s** at HEPA's to extend life.
- **N+1 banks** per wing; banks valved for isolation; *bag-in/bag-out* ports everywhere.
- Carbon graded by pore size (microporous for VOCs, mesoporous for semi-volatiles); include a **catalytic stage** if NOx/SOx suspected.

3.2 Overpressure doctrine (zones & numbers)

Why: leak inward from clean to dirty, never outward.

- **Setpoints (relative to ambient):** Clinic +40–50 Pa; Residential +25–35 Pa; Library/Class +25 Pa; Galley +15–20 Pa; Goods/Waste Locks 0 to –10 Pa (toward dirty side).
- **Gradients:** ≥ **5–10 Pa** step between adjacent zones; pressure doors fail-shut, latch in ≤5 s.
- **ACH:** 4–6 occupied; **10–12 purge** mode (≤10 min wing clear).
- **Controls:** PID on VFD supply fans with return dampers; **wind-compensating trim** from roof anemometer; loss of one fan ⇒ auto choke noncritical wings to preserve ΔP.

Rule of thumb: if ΔP oscillates with door traffic, you're under-ducted or over-occupied—add buffer volume or reduce setpoint by 5 Pa and increase supply CFM 10%.

3.3 Intake mounds disguised as dunes

Purpose: low-sign, low-entrainment in real wind.

- **Geometry:** teardrop planform aligned to trades; **crest offset** ≥ 8 m upwind of snorkel; **slot intakes** on leeward face behind a baffle.
 - **Grit arrest:** coarse cobble forebay + washable aluminum honeycomb; **drip edge** and gravel sump.
 - **Wash regime:** RO mist squeegee bots at dusk/dawn; wash liquor to sump $\rightarrow$ filters $\rightarrow$ IX; never recirculate on intake films.
 - **Security:** low silhouette, no shining metal; thermal mass to damp convection plume signature.
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3.4 Monitoring & interlocks

- **ΔP taps** across each stage (graph daily); **alarms** at +30% and +60% of clean ΔP .
 - **Flow & leakage:** traverse grid quarterly; door sweep tests; fog tracer at seams.
 - **Chemistry:** upstream/downstream **TVOC** and **acid gas** electrochem sensors; **CO₂** for occupancy; occasional sorbent-tube confirms.
 - **Fail-safes:** conductivity interlock on wash water; fan fire-mode (smoke purge) hard-wired; carbon bed bypass *impossible* (physical keys).
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3.5 Filter rationing curves (media budget)

When resupply is finite, air is a ledger.

Inputs: dust index (mg/m^3), door cycles/day, wind class (Trade/Kona/calm), current ΔP slope, media on hand (m^2 of MERV, H14, kg carbon).

Policy curves:

- **Prefilters:** swap by **ΔP -slope** not absolute ΔP (flattening = surface loading $\rightarrow$ brush/wash; steepening = depth loading $\rightarrow$ replace).
- **HEPA:** never wash; replace at **$\Delta P \geq 2 \times \text{new}$** or pinhole test fail; rotate bank duty (A/B) weekly to even load.

- **Carbon:** monitor **breakthrough** (downstream VOC ratio); “skid & flip” drawer order at 60% capacity; reactivated only if you have a kiln—assume **single-use**.

Rationing modes:

- **Green (normal):** full ladder online; ACH per spec.
- **Amber (preserve):** drop MERV 11 stage; raise prefilter face area by 2×; reduce ACH –10% in low-occupancy wings; tighten door closers.
- **Red (life-support):** isolate nonessential wings; ACH –20% in sleeping hours; elevate clinic ΔP +5 Pa; carbon to essential wings only.

3.6 The calculus of shutting wings to save media

A shut wing saves more than electricity—it saves *filters*.

Decision table (example):

Trigger	Action	Media saved	Comfort hit
Prefilter stock < 30 days @ current burn	Close least-used culture wing; purge, seal, drop to 0.5 ACH	~12–18% total m ² /day	Low
H14 ΔP slope > 1.5× baseline in ≥ 2 wings	Move residential to shared block; shut spare gallery	~1 bank’s life/month	Medium
Carbon breakthrough in ≥ 1 wing & <90 days carbon left	Carbon to clinic/residential only; galley on strict odor control	All carbon for critical spaces	Medium–high
Kona week forecasted	Pre-close windward wings; double prefilters on leeward; night-only fresh-air make	Limits HEPA load spike	Medium

Workflow: (1) Forecast & stock report at 06:00 → (2) “Air Budget” meeting (planner + clinic + mechanical) → (3) announce closures (08:00) → (4) purge & seal (by 20:00). Reopen only after two clean days and media audit.

3.7 Operations: daily/weekly/quarterly rhythms

- **Daily:** ΔP graph; VOC/ CO_2 check; intake wash if dust>threshold; door seals walk-by; odor audit (two noses).
 - **Weekly:** pinhole scan on one H14 row (rotating); carbon downstream spot-check; door closer speed set; sky-engine filter vacuum.
 - **Monthly:** full traverse on a wing; fog test a pressure door set; clean intake sump; calibrate TVOC.
 - **Quarterly:** swap prefilter frames (launder set); carbon drawer shuffle; verify purge clears wing ≤ 10 min.
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3.8 Numbers to design by

- **Supply air per person:** 10–14 L/s (residential), 20–25 L/s (clinic).
 - **Bank sizing:** 1.5–2.0 $\times$ peak **CFM** with one bank down.
 - **Leakage test:** < 0.5% of flow at 750 Pa across HEPA rack.
 - **Door sweep rate:** 3–5 s close; latch ≤ 1 s; pressure dip ≤ 5 Pa on pass.
 - **Carbon bed empty-bed contact time:** 0.2–0.4 s (faster for odor, slower for solvents).
 - **Intake mound standoff from grade dusters (roads, pads):** ≥ 40 m.
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3.9 Emergency modes (when air goes wrong)

- **Ashfall/Kona spike:** close all OA; **recirculate + carbon**; run interior cleanup; resume OA 02:00–06:00 only.
 - **HEPA rack breach alarm:** drop zone to Amber; purge *down* through dirty stack; suit-up bag-in/bag-out; carbon stays online.
 - **Sustained VOC rise (solvent spill):** isolate source wing; high-flow purge out dirty stack; swap carbon drawers in affected branch.
 - **Power shortfall:** collapse to life-support: clinic/residential only, ΔP minimal but positive, ACH 3–4, open buffer volumes.
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3.10 Human factors (morale is part of the air system)

- **Noise:** fans you can hear are fans you'll hate—keep <40 dBA in living spaces; add soft “trade-wind” masking.
- **Smell:** herb walls at returns, strict bans on scented products, carbon polishing on galley/latrine exhausts.
- **Light:** sky-engines sync with fresh-air windows; dimmer, warmer scenes during recirc periods to nudge behavior.

Bottom line: Power, water, and food are solvable with stores and pumps; *air is the clock*. A disciplined stack (sacrificial prefilters, H14 banks, carbon polish), coherent overpressure, stealthy intakes, and a ruthless media budget keep lungs and tempers steady—long after the island stopped helping.

4) Water: Sea to Cell

4.1 Source & intake: quiet coves, quiet hydraulics

Objective: pull stable feedwater with minimal entrainment and signature.

- **Geometry:** buried **cobble filter galleries** or wedge-wire laterals at **10–20 m depth**, leeward side of headlands; intake vault tucked into lava bench.
- **Screen velocity:** $\leq 0.15 \text{ m/s}$; dual laterals with cross-ties to hedge Konas.
- **Pre-screens:** coarse basket + honeycomb grit arrestor; wash with RO mist at dawn/dusk; liquor to sump → bag filters → IX.
- **Materials:** super-duplex (2507) or titanium Grade 2 in splash/ambient zones; FRP for low-pressure runs; cathodic protection on steel.

4.2 Pretreatment ladder (dirty → clean)

1. **Coagulation/Floc** (optional during blooms): low-dose ferric or chitosan; inline static mixer.
2. **DAF/Nano-bubble float** (if floc on): skimmer to sludge pan → filter press → drum.
3. **Dual Media Filters** (anthracite/sand + GAC polish): downflow; backwash with RO permeate; air scour sparingly.

4. **5 µm Cartridge Banks** (N+1): ΔP-monitored; bag-in/bag-out.
5. **Anti-scalant** (if not using softening IX): dose control tied to Langelier & S&D indices.

Targets: SDI15 ≤ 3, turbidity < 0.2 NTU to RO.

4.3 RO trains: redundancy, energy, and silence

- **Topology:** 2×50% or 3×50% trains (one warm standby) with ERDs (isobaric chambers).
- **Staging:** 2-stage, 6:3 (8" elements) for seawater; **Recovery 35–45%** (tuned to biofouling season).
- **Pressure:** 55–65 bar SWRO; feed pumps VFD-driven; surge bottles for quiet starts.
- **Elements:** low-fouling polyamide; staggered age across housings; rotate lead vessels monthly.
- **CIP:** acid + surfactant + biocide skids; **membrane mass balance** logged pre/post; hot-flush banned (aging).
- **Noise discipline:** pump vault on isolation pads, labyrinth inlets, < 65 dBA at door.

Outputs:

- **Permeate:** 200–350 mg/L TDS (post-blend); **Boron** trimmed by pH swing or second pass as needed.
 - **Brine:** 60–70 g/L TDS to diffuser (see 4.6).
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4.4 IX polish & finishing

- **IX racks:** small **mixed-bed** or **anion** polish for residual boron and taste after RO; **empty-bed contact** ~2–3 min; conductivity interlock.
 - **Remineralization:** calcite bed or CO₂ dosing to **Langelier SI ≈ +0.1 to +0.3**; target **Ca 20–40 mg/L**, **alk 40–80 mg/L**.
 - **Chlorination:** minimal free chlorine **0.2–0.4 mg/L** at distal taps; UV ahead of storage as non-chlorine barrier.
-

4.5 Distribution: color-coded loops (potable/gray/black)

- **Blue (Potable):** food-contact, clinic, residential; 316L or PEX-a; backflow preventers at every branch; looped mains with ≥ 0.3 m/s sweep velocity.
 - **Silver (Process RO):** lab/clinic machines, hydroponic make-up; isolated from blue; **no brass**, only 316L/PEEK/PTFE.
 - **Purple (Gray):** shower/laundry effluent to polishing MBR → irrigation of **indoor** planters only.
 - **Black:** toilets/galley to anaerobic MBR + aerobic polish; biogas to flare or micro-CHP; solids to press → drum.
 - **Color discipline:** fittings & valves dyed; visual inspection is the first audit.
-

4.6 Brine discharge: unpeopled embayments, high dilution

- **Diffuser:** multiport, 30–60° ports, **exit velocity 3–5 m/s**; elevation **+2–5 m** off bottom; oriented to longshore flow.
 - **Dilution goal:** $\geq 100:1$ @ **100 m** radius at mid-tide; verified quarterly by tracer (rhodamine) & CTD casts.
 - **Acoustic stealth:** mount under ledge, elastomer hangers; no cavitating valves.
 - **Fail-safe:** salinity and temperature probes on mast; auto-throttle trains if dilution < setpoint.
-

4.7 Corrosion & biofouling: the island's ticking clock

Corrosion:

- **Alloys:** titanium at intake/first lift; super-duplex in high- Cl^- spray; 316L inland; dielectric breaks at transitions.
- **Chem control:** maintain permeate **pH 7.0–8.0**; dose **orthophosphate** (trace) only in non-RO loops if needed; ban hypochlorite upstream of RO (membrane-safe biocide only).
- **Inspection:** UT wall checks annually; coupon racks in brine room; stray-current survey quarterly.

Biofouling:

- **Intake:** periodic **chloramine slug** or peroxide-based biocide on gallery (membrane-safe); backflush laterals on neap tides.
 - **Pretreat:** DAF on blooms; keep filter backwash **with RO permeate**; sanitize housings at each cartridge swap.
 - **RO:** watch **dP rise rate** (mbar/day); CIP trigger on slope + normalization drop; off-season low-T recovery bump to starve bugs.
 - **House loops:** $\leq 25\text{ }^{\circ}\text{C}$ storage; recirc to avoid dead legs; periodic thermal shock ($60\text{ }^{\circ}\text{C}$) on purple loop only.
-

4.8 Storage & headworks

- **Potable tanks:** dual **day tanks** (N+1), epoxy-lined, floating bladders; level alarms; nitrogen blanket optional for taste.
 - **Process RO tanks:** small, jacketed, strictly segregated; conductivity interlock to Blue.
 - **Fire reserve:** separate cistern; non-potable; cross-connection *physically impossible*.
 - **Headworks pit:** flood sensors; sump to filter press; all drains trapped & test-tee'd.
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4.9 Controls, monitoring, and interlocks

- **Core sensors:** turbidity, SDI, ΔP each pretreat stage; RO feed/reject/permeate flow & pressure; conductivity (in/out); boron (weekly wet-chem), pH/alkalinity/Ca.
- **Interlocks:**
 - High SDI $\rightarrow$ drop recovery, raise crossflow, pre-CIP alert.
 - Conductivity spike post-RO $\rightarrow$ divert to process tank, lock Blue.
 - Brine dilution low $\rightarrow$ stage down trains, wait for tide/wind.
- **Dashboards:** “Water Budget” tile with **days-of-membranes**, **IX exhaustion clock**, **CIP debt**, **brine dilution**.
- **Records:** membrane normalization curves; CIP logs with permeate quality delta; IX bed throughput (bed volumes to breakthrough).

4.10 Operations cadence (what the crew hears)

- **Daily:** intake wash; SDI & turbidity trend; ΔP slopes; taste/odor check at distal tap; brine mast probe snapshot.
 - **Weekly:** cartridge change (if ΔP slope), backwash filters; IX quick-rinse test; remineralization titration.
 - **Monthly:** one-train CIP; diffuser tracer run (if seas permit); storage tank inspection port wipe; corrosion coupons read.
 - **Quarterly:** membrane rotation; calcite media top-up; full chemistry panel; cathodic protection check.
 - **Annual:** intake gallery inspection (ROV); UT thickness survey on lift lines; brine diffuser ROV video.
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4.11 Numbers to design by (quick table)

Parameter	Target	Note
Intake depth	10–20 m	Below scum, above scour
Screen face velocity	≤ 0.15 m/s	Low entrainment
Pretreat SDI ₁₅	≤ 3	To RO
SWRO recovery	35–45%	Seasonally tuned
RO specific energy	2.5–3.5 kWh/m ³	With ERDs
Permeate TDS	200–350 mg/L	Post-blend
LSI at taps	+0.1 to +0.3	Scale-neutral
Residual chlorine	0.2–0.4 mg/L	Distal
Brine dilution	$\geq 100:1$ @100 m	Mid-tide
Storage autonomy	48–72 h	At average load

4.12 Failure modes & triage trees

- **Bloom + SDI spike:** cut recovery to 30%, bring DAF online, double backwash cadence, stand up warm spare train; ration showers; prioritize **Blue** → clinic.
 - **Membrane oxidation (accidental chlorine):** immediate neutralization; isolate train; swap first-stage elements; normalize curve audit.
 - **Boron exceedance:** second-pass RO or pH-swing + boron-selective resin; divert to **Process** until within spec.
 - **Biofouled IX:** bed swap; sanitize vessel; confirm breakthrough with field kit before reconnect.
 - **Diffuser damage (storm):** throttle trains to not exceed interim dilution; temporary surface outfall at slack tide under ledge; repair on next window.
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4.13 Human factors: taste, trust, and rituals

- **Taste:** tune remineralization for mouthfeel; avoid “flat” water—small Mg/Ca makes morale.
- **Signals:** gentle chime when Blue loop returns to spec after maintenance; “low-tide” lighting scene during brine throttling to cue conservation.
- **Stories:** post the weekly **Water Budget** (days of membranes, IX %, brine health). The sound the bunker hears is pumps; the clock it reads is **membrane life**.

Bottom line: In a dead archipelago, water is a **machine you serve**. Quiet intakes, disciplined pretreatment, conservative RO with IX polish, sober brine hydraulics, and color-coded loops turn the sea into cells and kitchens day after day—until the membranes, and your patience, run out.

5) Power: Sun, Salt, and Silence

5.1 PV canopies in bermed courtyards

Purpose: make electricity without advertising your existence.

- **Form:** low-profile pergolas inside **bermed courtyards**, panel planes **10–15°** to shed dust; edges knife-trimmed to break vortices.

- **Modules:** glass–glass bifacial (salt-hard), bypass diodes accessible; **string fusing** in pull-out trays behind acoustic louvers.
- **Cleaning:** RO mist + squeegee bots at dawn; dust sensors drive cycles; no dry brushing.
- **Wiring:** UV crosslinked cable in **salt-rated conduit**; homeruns to sub-court combiner, then underground to DC room.
- **Thermal:** 150–200 mm standoff; airflow baffles that don't whistle; back-of-module temp < 65 °C (P95).
- **Security:** no specular glint (etched glass); panel edges masked from aerial view; canopy parapets match soil color.
- **Sizing cue:** roof + court area of **18–24 m²/person** (bunker-grade frugality) → 3–5 kWp/person at 1 kW/m² peak.

5.2 Baffled micro-wind (when trades help, Konas don't)

- **Turbines:** slow-RPM, **direct-drive** 3–5 kW class with marine coatings; mast h ≤ parapet + 3 m; **teardrop baffles** upwind to kill tonal noise.
- **Siting:** in **lee accelerators** along berm gaps; avoid salt plume; anemometer + wind rose baked into siting.
- **Controls:** curtail above **12–14 m/s** or in Kona gusts; soft-stop yaw to avoid clack; night curfew if acoustic floor rises.
- **Maintenance:** quarterly blade wipe; annual balance; lightning down-conductors to buried grid.

5.3 Storage underground: batteries, ventilation, H₂ detection

- **Chemistry:** LiFePO₄ blocks for daily cycling; small **LTO** or supercaps for surge/teleop; thermal mass from surrounding rock.
- **Room:** concrete cell with **2-hour fire rating**, intumescent paint; floor trenches to neutralization sump; **blast-relief panel** to sand pocket.
- **Ventilation:** push-pull ducting; **redundant EC fans**; airflow ≥ **6 ACH** normal, **20 ACH** emergency.
- **Detection:** H₂ sensors at crown, CO/CO₂/temperature arrays; interlocks trip chargers & open dampers upon alarm.

- **Isolation:** DC contactors per rack; arc-flash boundaries painted; **dead-front** switchgear; fiber comms, not copper, across rooms.
- **Capacity target:** **20–36 hours** autonomy at average load, with **N+1** inverter stacks.

5.4 Liquid fuels & green H₂ as grace-notes

- **Biodiesel** (B20–B50) day-tank in bunded vault; **hospital-grade genset** on inertia pads; load bank exercises monthly at night.
- **Green H₂** (if local overbuild): 5–15 kg buffer in ventilated cabinet; **PEM fuel cell** 5–20 kW for silent nights and clinic priority.
- **Fuel discipline:** never co-site fuels with batteries; vapour detection + forced vent; transfer hoses with dry-breaks only.
- **Use policy:** genset for **CIP/RO surges** and prolonged Kona gloom; H₂ for **clinic, radios, air spine** during acoustic stealth windows.

5.5 Power electronics & distribution

- **Topology:** PV strings → **DC bus** → HVDC ring (± 380 –750 V) → modular inverters feeding **clean** and **dirty** AC buses (separable).
- **Selective loads:** clinic HVAC, air spine, RO low-lift pumps, comms on **clean bus**; shops, kitchens, laundries on **dirty bus**.
- **Fault management:** sectionalized rings, **solid-state breakers**, and tie points; auto-isolate on ground-fault or arc-fault.
- **Grounding:** buried counterpoise; surge arresters at every outdoor run; equipotential grid in battery/genset rooms.
- **EMI hygiene:** shielded cabinets, ferrites on long DC runs; inverter carriers spread-spectrum; radios on orthogonal bands.

5.6 Acoustic & signature discipline

- **Targets (A-weighted):** courtyard edge < **40 dBA** nights; mechanical doors < **55 dBA**.
- **Treatments:** labyrinth intakes, micro-perforated panels, mass-loaded vinyl behind louvers, elastomer feet everywhere.
- **Ops:** loud work (backwash, CIP, load-bank, genset test) in **trade-wind noon**; silent scenes (clinic/night) on fuel cell + battery.

- **Optical:** matte finishes; thermal muffling on exhaust; avoid hot plumes visible to IR from above.

5.7 Controls: the Power Budget and load shed ladder

- **Budget tile:** SoC hours, PV forecast (kWh), RO/CIP debt, clinic reserve, **silent-mode window**.
- **Ladder (auto-shed with manual veto):**
 1. Decorative lighting → 2) Laundry/dish heaters → 3) Hydroponic lights (rotate crops) → 4) Workshop tools → 5) Galley hobs (to induction-1 only) → 6) RO 2nd pass → 7) Gallery HVAC setpoints widen → 8) Non-critical wings purge only.
- **Quiet mode:** caps fans, parks wind, swaps to fuel cell, slows pumps, enforces ≤ 300 W/person house load.
- **Storm/Kona mode:** parks wind, raises PV tilt if adjustable, shifts RO to night.

5.8 Operations cadence & spares

- **Daily:** PV soiling index; SoC drift; inverter temp; wind curtail log; genset fuel check; noise walk.
- **Weekly:** combiner thermal scan; torque on busbars; H₂ sensor test; clean intake screens on battery/genset rooms.
- **Monthly:** load-bank genset (30–60 min); fuel cell stack health; lightning inspection; DC insulation resistance test.
- **Quarterly:** swap one inverter module to prove hot-spare; blade balance check; PV IV-curve sampling (10%).
- **Spares:** 10–15% PV modules, one full inverter stack, fan sets, bearings, filters, coolant, contactors, fuses, belts; 1–2 spare RO VFDs (shared with pumps).

5.9 Numbers to design by (quick table)

Parameter	Target	Note
PV capacity	3–5 kWp/person	Frugal bunker profile
Battery autonomy	20–36 h	Avg load, N+1 inverters
Round-trip efficiency	≥ 85%	Battery + inverter
Wind cut-in / cut-out	3–4 / 12–14 m/s	Curtail for acoustics
Genset sizing	0.6–0.8× peak	For RO + HVAC surge
Fuel cell	5–20 kW	Silent priority loads
Mech room noise	< 55 dBA	At door, P95
Courtyard night noise	< 40 dBA	At perimeter
HVDC ring	±380–750 V	Lower loss, sectionalize

5.10 Failure modes & triage

A) Week-long Kona gloom

- Action: Quiet mode; stop wind; fuel cell continuous; **genset 2–3 h/day** for RO + battery top; stagger hydro lights; widen HVAC setpoints.
- Revert: after PV forecast > load + 20% margin for 24 h.

B) Battery room H₂ alarm

- Action: Trip chargers; open dampers; purge to **20 ACH**; thermal scan racks; resume in stages; investigate cell(s).
- If repeat: isolate rack; derate SoC ceiling 10%.

C) Inverter stack failure

- Action: sectionalize DC ring; shift clinic/air spine to healthy stack; shed Level 3+; hot-swap module; run fuel cell/genset if needed.

D) PV string ground fault (salt creep)

- Action: Open combiner; IR inspect; clean/retape; insert spare optimizer/diode; schedule deeper wash.

E) Wind acoustic complaint (self-detect)

- Action: Curtail to 50% RPM; add leading-edge tape; re-balance; if persistent, night curfew for that mast.

F) Fuel contamination

- Action: Swap to day-tank B-line; polish main tank; change filters; sample daily for a week.

5.11 Human factors: how power feels

- **Cues:** subtle wall LED shows **green/amber/red** budget; “trade-wind noon” sound mask rises when loud work runs; “silent mode” dims and warms light scenes.
- **Etiquette:** induction hobs share, dryers queue, headphones at night; power discipline is culture.
- **Stories:** weekly **Power Budget** posted: days of diesel/H₂, battery health, PV soiling, quiet-window hours.

Bottom line: Sun for bulk, wind for trimming, batteries for rhythm, fuels for grace—and quiet always. Power that people **don’t notice** is power that keeps them calm, hidden, and alive.

6) Food Without Fields

6.1 System stack at a glance (closed but not brittle)

- **Tiered hydroponics:** two bands—**Leafy** (fast-cycle, low-light) and **Fruiting** (slower, high-light).
- **Fungi:** **mushroom racks** for protein, umami, and Vitamin D (post-harvest light).
- **Insects:** **black soldier fly (BSF) + crickets** to turn peels and spent biomass into oils, chitin, and meal.
- **Aquaculture:** **RAS** (recirculating aquaculture system) for tilapia or milkfish; small **bivalve scrubbers** if makeup water allows.
- **Pantry:** sealed, lot-tracked **legacy stocks** as a financial balance sheet—drawdown rules, hedges, and audits.

- **Governance:** a weekly **Food Budget** meeting (chef + hydro lead + RAS tech + pantry treasurer).
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6.2 Tiered hydroponics

A) Leafy tier (fast-cycle)

- **Crops:** lettuce mixes, chard, kale, bok choy, arugula, basil, cilantro.
- **Method:** **Deep Water Culture (DWC)** rafts + **NFT** gullies for herbs.
- **Cycle:** 21–35 days (seed→harvest).
- **Lighting:** 150–250 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPFD, 14–16 h photoperiod; far-red bump 5–10 min at close for compactness control.
- **EC/pH:** 1.2–1.8 mS/cm; pH 5.8–6.2.
- **Yield cue:** **2.0–3.0 kg/m²/month** mixed.

B) Fruiting tier (slow-cycle)

- **Crops:** cherry tomato, pepper, cucumber, dwarf eggplant, determinate bush beans, strawberries.
- **Method:** **coco/perlite drip** in bags or buckets with drain-to-reservoir (recirc) and pathogen UV loop.
- **Cycle:** 60–120 days; staggered to weekly pick cadence.
- **Lighting:** 300–450 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPFD, 16 h; night temp setbacks.
- **EC/pH:** 2.0–3.0 mS/cm; pH 5.5–6.0; crop-specific recipes (e.g., K for fruiting).
- **Yield cue:** **3–6 kg/m²/month** (tomato/pepper/cuke mix) in bunker-grade regimes.

C) Water & air discipline

- RO make-up only; **UV + 1 μm** polish on recirc loop.
- **Dissolved oxygen:** ≥ 6 mg/L (leafy), ≥ 7 mg/L (fruiting).
- **Biosecurity:** foot bath, glove stations, crop-lane one-way; weekly pathogen PCR (Pythium/Phytophthora/Clavibacter) if kits available.
- **IPM (no aerosols):** yellow/blue cards, sticky roll, manual cull, Beauveria/BT where necessary inside containment tents.

D) Nutrient concentrates (two-tank A/B + micros)

- **A:** $\text{Ca}(\text{NO}_3)_2$, KNO_3 .
- **B:** MgSO_4 , KH_2PO_4 .
- **Micros:** Fe-EDDHA, Mn, Zn, Cu, B, Mo; **silicate** for cell strength.
- **Mix log:** EC/pH before & after; temperature; batch ID; operator.

E) Light & heat budget

- **Leafy:** 25–40 kWh/m²·month.
 - **Fruiting:** 70–120 kWh/m²·month (LED efficacy 2.5–3.0 $\mu\text{mol/J}$).
 - Waste heat reclaimed to **pre-warm domestic hot water**.
-

6.3 Fungi: mushroom racks

- **Species:** oyster (*Pleurotus*), shiitake (*Lentinula*), lion's mane (*Hericium*).
 - **Substrates:** pasteurized straw + soybean hulls; sterilized supplemented sawdust blocks (for shiitake).
 - **Rooms:**
 - **Incubation:** 22–24 °C, 60–70% RH, dark, CO_2 3–5k ppm.
 - **Fruiting:** 14–18 °C (oyster), 85–95% RH, CO_2 < 1k ppm, 500–800 lux diffuse.
 - **Cycle:** 3–5 weeks per flush; 2–3 flushes.
 - **Yield cue:** **15–25% BE** (biological efficiency) per flush; **40–60% BE** total.
 - **Sanitation:** positive-pressure entry, hydrogen peroxide surface wipe, no bleach aerosols.
 - **Vitamin D:** 5–10 min **UVB** post-harvest boosts D2.
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6.4 Insects: BSF + crickets

- **BSF (*Hermetia illucens*):**
 - **Role:** convert veg trimmings & spent substrate to **larval biomass (35–45% protein, 25–35% fat)**.
 - **Bins:** stacked, gasketed; 27–32 °C, 60–70% RH; harvest at 14–18 days.

- **Outputs:** oil (cooking blend/candle), **meal** (aquaculture feed), **frass** (hydro micronutrient supplement—sparingly, filtered).
 - **Crickets (*Acheta domesticus*):**
 - **Role:** human protein/texture; roasted powder into flatbreads/pastas.
 - **Bins:** 26–30 °C, 50–70% RH; egg flats; harvest at 6–8 weeks.
 - **Hygiene:** no aerosol sprays; HEPA exhaust; scald & roast kill-step; chitin saved for bioplastics/bandages.
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6.5 Aquaculture: RAS for fish + bivalve scrubbing

- **Species:** tilapia/milkfish (tolerant), optional **shrimp** if biosecurity strong.
 - **Tanks:** 5–10 m³ modules; **stocking 20–40 kg/m³**; swirl separators, MBBR biofilters, foam fractionator.
 - **Water:** RO + remineralized; salinity 0–5 ppt (tilapia), 10–20 ppt (milkfish).
 - **O₂:** diffusers or low-shear pumps; **≥ 6 mg/L**.
 - **Feed:** BSF meal + formulated; FCR **1.1–1.5**.
 - **Bivalves:** small side-stream mussel/clam module (if seawater access) for fine particulate polish; **not for eating**—biomonitor & filter only.
 - **Yield cue:** **40–60 kg/m³/year** (conservative).
 - **Waste:** settle → belt filter → **anaerobic digester** (biogas) → press cake to drum.
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6.6 Palate vs membrane: recipe cycles that respect filters

- **Constraint:** RO membranes and HEPA/carbon capacity set upper bounds on cooking moisture, aerosol, and odor loads.
- **Culinary tactics:**
 - **Wet days / Dry days:** cluster stews, noodle boils, and sterilizations on **high-power, high-vent** windows; bake/roast on **quiet days**.
 - **Low-splash prep:** blanch → chill → finish in oil (minimal steam).
 - **Smell traps:** pressure-tight lids; carbon-polished hoods; gaskets on ovens.

- **Menu math:** **Leafy base** (salads, wraps, soups), **Fruiting spikes** (tomato sauces, pickled cukes), **Fungi umami**, **Fish weekly**, **Insect protein** folded into pastas and flatbreads.

Example 7-day bunker menu (per person, illustrative)

- **Mon:** herb salad, mushroom miso, tilapia rice bowl (leafy+fish).
- **Tue:** tomato–basil pasta (cricket flour), roasted peppers & onions, strawberry cups.
- **Wed:** bok choy & tofu stir-fry, cucumber pickle, sesame greens.
- **Thu:** fish cakes (BSF/tilapia blend), kale slaw, seaweed rice (iodine).
- **Fri:** shiitake stew with barley, arugula & citrus vinaigrette.
- **Sat:** pizza night (LED tomatoes), lion’s mane “crab” cakes, basil pesto.
- **Sun:** ramen (leafy tops, soft egg), pickled veg, baked custard (powdered milk reserve).

Micronutrient checks: **iodine** via seaweed ration, **B12** via fortified pantry + mushrooms, **omega-3** via fish/algals.

6.7 Pantry as treasury: lots, hedges, and drawdown rules

- **Lots:** refined grains, oils, sugar, salt, dried legumes, milk powder, vitamin/mineral mixes, spices, tea/coffee/cocoa.
- **Ledger fields:**
lot_id, item, vendor, pack_date, est_shelf_end, storage_zone, qty, assay(if any), open_date, daily_draw, safety_floor, hedge_ratio
- **Hedges:** diversify by supplier/pack date; **oil** across olive/canola/BSF; **protein** across legumes/fish/insects.
- **Drawdown rules:**
 - **FIFO within floor:** never drop below **90 days** of each class.
 - **Hedge burn:** when one class spikes in use (e.g., noodles), throttle to 80% and rotate to legume/protein days.
 - **Festival buffer:** keep 2–3 “morale lots” (chocolate, coffee) untouchable except on scheduled feast days.

Audits: monthly bin count + random assay (rancidity in oils, moisture in grains). **Appeal path:** chef can request emergency release with two signatures (clinic + treasurer).

6.8 Space, power, labor (thumb rules)

Subsystem	Area	Power	Labor
Leafy hydro	0.6–0.8 m²/person	30–50 W/m ² avg	0.5–1.0 hr/m ² ·wk
Fruiting hydro	0.8–1.2 m²/person	80–150 W/m ² avg	1.0–1.5 hr/m ² ·wk
Mushrooms	0.1–0.2 m²/person	10–20 W/m ²	0.3 hr/m ² ·wk
Insects	0.05–0.1 m²/person	5–10 W/m ²	0.2 hr/m ² ·wk
RAS fish	0.05–0.1 m²/person (tank plan)	5–15 W/person	0.2 hr/m ³ ·day
Pantry	0.3–0.5 m²/person (shelving)	n/a	0.1 hr/m ² ·wk

6.9 Hygiene & biosecurity (non-negotiables)

- **People flow:** clean smocks, hair covers; hand/boot hygiene; **no cross-over** from insects→mushrooms→hydro without change.
 - **Air:** each room its own micro-ΔP; returns through **carbon + HEPA** near kitchens.
 - **Water:** purple (gray) never touches hydro or RAS; **process RO** separate from **Blue** (potable).
 - **Kill-steps:** blanching, roasting, pickling; **pH < 4.2** where appropriate; salt/sugar cures logged.
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6.10 Failure modes & triage

A) LED failure (string/driver)

- **Action:** rotate crops to lit bays; harvest early; increase reflective films; shift menu toward mushrooms/legumes; repair within 72 h.

B) Pythium bloom (leafy)

- **Action:** isolate raft; UV shock loop; hydrogen peroxide pulse; cull symptomatic; reseed nursery; sanitize gullies.

C) Tomato russet mite / whitefly

- **Action:** quarantine tent; remove heavily infested; release beneficials if available; escalate to crop reset.

D) RAS oxygen drop

- **Action:** emergency O₂ injection; reduce feed; partial water change; check blower/stone fouling; log FCR after event.

E) Pantry breach (rodent, moisture)

- **Action:** isolate rack; discard compromised; desiccant refresh; inspect seals; adjust HVAC dehumidification.

F) CO₂ shortages (for photosynthesis boost)

- **Action:** accept slower growth; compensate with photoperiod; prioritize leafies; pause high-demand fruiting.

6.11 “Food Budget” dashboard (daily operator view)

- **Produce:** kg harvested today / kg target; days-to-harvest by crop.
- **Nutrients:** EC/pH bands; concentrate days remaining.
- **Energy:** kWh to food (24 h); waste heat recovered (kWh).
- **RAS:** biomass kg; FCR last 7 days; DO min/avg.
- **Insects:** BSF larval kg; frass kg diverted; oil stock (days).
- **Pantry:** days-of-grain, days-of-oil, feast buffer; hedge parity index.
- **Alerts:** pathogen PCR overdue; EC drift; filter change; LED outliers.

6.12 Lived cuisine: making bunker fare feel like home

- **Textures:** mushrooms for chew, crickets for crunch, noodles for comfort.

- **Acids & pickles:** keep a rotating wall—cukes, radish, green mango—low-power, high-morale.
- **Herb culture:** basil, shiso, mint, cilantro—small watts, big lift.
- **Rituals:** weekly pizza/pasta night (fruiting tier); fish Friday; feast days unlock morale lots (coffee, cocoa, preserves).
- **Story:** menu cards show “**watt-minutes & water liters**” per dish—pride in efficiency becomes taste.

Bottom line: In a sealed Maui, fields are memories—but kitchens don’t have to be. Stack hydro, fungi, insects, and fish; pace recipes to respect membranes and filters; run the pantry like a treasury. Do this, and people eat well enough, long enough, to remember why living was the point.

7) Waste: Nothing Leaves Dirty

7.1 Flows & doctrine (design once, violate never)

- **One-way hygiene:** dirty → contained → treated → **measured** → released or **drummed**. No exceptions for convenience.
- **Four streams:** **Black** (toilets/galley), **Gray** (showers/laundry), **Process** (hydro/RAS blowdown, CIP), **Solid** (filters, wipes, sludge cakes, ash).
- **Rule of release:** if it hasn’t passed its **spec & sensor** gates (chemistry + gamma), it doesn’t leave the envelope—it **drums**.

7.2 Blackwater: anaerobic + aerobic bioreactors (ABR → MBR)

Train (dirty → clean):

1. **Screen box** (3–6 mm) → bag & drum screenings.
2. **Grease trap** (galley only) → skims to drum.
3. **Anaerobic baffled reactor (ABR):** HRT 24–48 h; biogas to micro-CHP/flare.
4. **Equalization tank** (pH/flow smoothing).
5. **Membrane bioreactor (MBR):** 0.04–0.1 µm hollow fiber; MLSS 8–12 g/L; **UV** post.
6. **Polish:** GAC column (optional); **IX** for specific ions if needed.

7. **Routing:** to **Purple** (indoor irrigation) or to **Blue** make-up (only if chemistry & radiological gates pass—rare/last resort).

Numbers to design by

- **COD removal:** 90–95% (ABR+MBR).
- **Permeate turbidity:** < 0.2 NTU.
- **UV dose:** $\geq 40 \text{ mJ/cm}^2$.
- **MBR flux:** 12–20 L/m²·h; backpulse every 10–15 min; CIP weekly if TMP slope rises.

Sludge & gas

- **WAS** (waste activated sludge) to **belt press** → cakes (25–35% solids) → **shielded drums**.
- **Biogas:** scrub H₂S (iron sponge), **CH₄ 55–70%** to micro-CHP (night heat or battery top-off); flare if storage low.

7.3 Graywater: polish & reuse (never crosses Blue)

Train: hair trap → **MBR-lite** (lower MLSS) or **sand + GAC** → UV → **Purple loop** (planters, flush).

- **Design:** keep Purple isolated (color-coded pipe/valves); **dye test** quarterly to prove segregation.
- **Targets:** turbidity < 1 NTU, residual free chlorine 0.2–0.4 mg/L (if chlorinated), HPC < 500 CFU/mL.
- **Odor control:** carbon vent filters; no aerosols.

7.4 Process water: hydroponic/RAS/CIP blowdowns

- **Hydroponic brine:** batch to **neutralization pit** (pH 6.5–8.5), EC logged; if salts high, blend with blackwater EQ (micro-nutrient) or **drum** small volumes to avoid plant shock.
 - **RAS purge:** fine solids to **rotary drum filter** → press → drum; filtrate to ABR/MBR.
 - **CIP rinses (RO/MBR):** capture acid/alk, neutralize to within spec; store for **non-potable wash** if clean; otherwise **drum**.
-

7.5 Solids chain: from rag to drum yard

Sources: screenings, grease, MBR sludge cakes, bag/cartridge filters, HEPA/IX cassettes, spent carbon, wipe pads, ash.

Handling doctrine

- **Yellow bench** (negative-pressure alcove) for bagging; **bag-in/bag-out** ports; double-bag, zip-tie, barcoded.
- **Press cakes:** floor fines & sump sludge to **filter press**; liners weighed; cakes drummed while damp (dust control).
- **Ash** (incinerator/pyrolyzer, if used): cool in closed pan; wetting allowed; drum with **ash passbook** (burn temp, load ID).
- **Spent carbon & IX:** drain, cap, **drum by vendor lot**; no home regeneration unless kiln/licensing exist (assume **single-use**).

Drum spec & yard layout

- **Drums:** UN-rated steel, bolt ring; absorbent liner; **gamma tag**; painted stripe by activity band (green/amber/red = internal code, not hazard placard).
- **Yard:** leeward of living block; **curbed concrete**, sump to press; rows on **gravel plinths**; shade awning to limit rain ingress; RFID grid for slots.

Log schema (append-only)

drum_id, stream(screen/grease/sludge/filter/HEPA/IX/carbon/ash),
mass_kg, water_content%, prebag_gamma_cps, postbag_gamma_cps,
origin_unit, date_time, operator_pseudo, photoset_url, row_slot,
notes(anomalies/odor/leak)

7.6 Radiological & chemical gates (release vs drum)

- **Liquids (to environment):** salinity, pH, turbidity, $\text{NH}_3\text{-N}$, $\text{PO}_4\text{-P}$, TPH; **gamma count** (60–120 s) at standard geometry; **release only** when all within setpoints.
- **Solids:** swipe test (smear) at bag; handheld gamma; if either over threshold → **drum**.
- **Airlocks:** waste locks run **air-knife** → **mist** → **gamma gate** on bins/hoppers before crossing to dirty yard.

Setpoints (illustrative, bunker-internal)

- pH 6.5–8.5, turbidity < 1 NTU to Purple, < 0.5 NTU to environment; ammonia < 1 mg/L; oil/grease < 5 mg/L.
 - **Gamma MDAs** documented per geometry; “K-rich only” notes acceptable; any anthropogenic line → **hold** or **drum**.
-

7.7 Incineration / pyrolysis (optional, tightly fenced)

- **Use cases:** volume reduction of **pathological solids** (wipes, contaminated organics).
 - **Preference:** **low-oxygen pyrolysis** (biochar) at 450–600 °C with ceramic candle filters → quench → char to **drum**; off-gas to **thermal oxidizer** + carbon.
 - **Absolute bans:** open burning; chlorine-bearing feeds without scrubbing; venting without carbon polish.
 - **Metrics:** mass reduction ≥ 70%; dioxin surrogate checks if kits exist; stack temp & ΔP logged.
-

7.8 Odor & aerosol discipline

- **Negative pressure** in waste rooms; **carbon + HEPA** on exhaust; no spray cleaners—**wipe only**.
 - **Dewatering:** press inside enclosure; mist curtain at discharge chute; **curb socks** on wash pads.
 - **Housekeeping:** hydrated lime for slicks, not as deodorant; daily squeegee to trench; weekly **white-glove** (cloth swipe) audit.
-

7.9 Operations cadence

Daily

- Screen/grease checks; MBR TMP trend; EQ pH; belt press run & yard walk (leaks/labels).
- Log **drum_in/day** and **yard_free_slots**.

Weekly

- UV intensity check; carbon headloss; CIP MBR if TMP slope > threshold; sludge %TS assay.
- Drum yard **gamma scan** transect; repaint marks; rodent proofing sweep.

Monthly

- ABR sludge depth sonar; gas H₂S tube checks; flare test; dye-test Purple segregation; pressure-wash yard with **captured liquor**.

Quarterly

- Full compliance snapshot: liquids chemistry panel, random drum smear audits, filter press cloth service, sump clean-out.

7.10 Numbers to design by (quick table)

Item	Target	Note
ABR HRT	24–48 h	Load-leveling
MBR MLSS	8–12 g/L	Stable flux
MBR flux	12–20 LMH	Backpulse 10–15 min
UV dose	≥ 40 mJ/cm ²	Post-MBR
Belt press dryness	25–35% TS	Cake to drum
Yard capacity	≥ 12 months @ median drum/day	With 20% surge
Negative pressure (waste room)	–10 to –25 Pa	To dirty stack
Sump freeboard	≥ 20%	Alarmed

7.11 Failure modes & triage

A) MBR fouling / TMP runaway

- **Action:** switch to standby cassette; relax flux; enhanced backpulse; chemical clean (citric/bleach—sequence, membrane-safe); **divert** excess to EQ with **strict water ration** for 24–48 h.

B) ABR souring (VFA spike, low pH)

- **Action:** add alkalinity (NaHCO_3); reduce load; recirculate effluent; seed from healthy digester (if any). Monitor gas H_2S .

C) Odor event / aerosol complaint (internal)

- **Action:** raise exhaust ACH; check enclosure seals; swap carbon; fog test room; schedule deep clean during **trade-wind noon**.

D) Yard overflow risk (drums > 85% capacity)

- **Action:** **waste drought** declarations: tighten wash cycles, defer non-critical press runs, compress packaging flows; reorganize rack to high-density; designate **aux yard** pad.

E) Gamma gate false/true positives

- **Action:** extend count time; verify geometry; if persistent line (anthropogenic), escalate to **Hold** → **Drum**; annotate log.

7.12 The moral horizon: living with the drum yard

When the island is gone, **waste is biography**. Each drum bears a date, a job, a smell you tried to keep in its bag. The yard grows like rings in a tree: a storm week here (filters and fines), a clinic month there (sharps and wipes), a harvest season of roots and skins pressed flat. You budget air and water with pumps; you budget **time** with drums. Design the yard as a place of **order and witness**—curbs, shade, labels you can read when tired—because it is the only history you will leave for a while.

Bottom line: Nothing leaves dirty. Liquids pass gates or circle back; solids are pressed, bagged, and **counted**. The system is unglamorous—screens, bugs, membranes, drums—but it is civilization's hinge in a sealed Maui. The day you skip a bag, a gasket, or a log is the day the bunker stops being safe.

8) Robotic Exterior — perimeter, pathway, quarry

8.1 Street & intake-corridor hygiene (HEPA sweepers + sticky rollers)

Goal: keep intake plumes clean and keep fines out of gutters and in drums.

Fleet & tools

- **Sweep mules (UGV):** low-CG, HEPA vac head (ΔP sensed), sticky-roller cassette, curb broom, on-board gamma puck.
- **Catch-basin kit:** vacuum wand + grate lifter; curb socks for wet work.

Route logic

- **Greenways:** intake corridors from pump houses → garages → air mounds (primary), feeder alleys (secondary).
- **Cadence:** high (daily) on primaries, low (2–3×/wk) on secondaries; **storm-eve** pass mandatory.

Playbook: “Clean-to-Catch”

1. Shoulder sweep → curb sweep → ΔP -guided HEPA pass.
2. Sticky-roller on seams & expansion joints.
3. Lift grate; vac sump to pan; sock if wet work; photo “clean grate.”
4. Tote fines to **waste lock**; receive **wash ticket** before next route.

KPIs

- PM fall at intake mounds ↓ **≥40%** vs baseline.
- Grate dwell ≥ **8 s** each; **100%** of primaries served daily.
- First-pass wash release of sweep heads **≥98%**.

8.2 Roof & gutter discipline (gutter crawlers + roof mules)

Risk: dust + leaf litter → ember beds → ignition + lofted fines.

Fleet & tools

- **Gutter crawler:** tracked mini, HEPA wand, squeegee fin, nozzle.
- **Roof mule:** tetherable UGV with vac head, squeegee bar, debris pan.

- **PV wash boom:** RO mist + squeegee; EC interlock.

Playbooks

- **R-Clean:** perimeter serpentine → field pass → parapet edge push; ΔP drives brush height.
- **G-Purge:** vac 2–3 m segments → squeegee → flow puck test downspout; jet if < threshold.
- **PV-Wash:** wind < 7 m/s; RO only; no soaps; conductivity gate < 40 $\mu S/cm$.

KPIs

- Roof dust mass removed/1000 m² tracked; re-loft PM ↓ **≥30% WoW**.
 - Downspout verified flow = **100%** on route; repeat blockages < **5%/mo**.
 - PV output **≥ 95%** of nameplate (irradiance-normalized).
-

8.3 Utilities: valves, clamps, hydrants (manipulators with torque heads)

Objective: keep water and power within compound spec; treat public grids as orphaned assets serving *you*.

Fleet & tools

- **Utility crawler:** torque head (5–150 N·m), saw (shrouded), clamp kit, leak acoustics, chloride strips.
- **Boom base:** 6-DOF arm for switchgear & insulators; portable shield kit.

Playbooks

- **V-PM (valve):** open/close cycle; torque curve logged; box vac & photo; tag stuck valves for swap.
- **Leak-Clamp:** UAV thermal confirm → crawler triangulates → partial isolation → wrap clamp → torque to spec → acoustic drop **≥10 dB**.
- **Hydrant-Service:** brush threads, grease, flow test to tote, cap; GPS log for next run.

KPIs

- First-response to utility alarm **≤ 15 min**; temp-restore water/power **≤ 60 min**.
- Torque curves captured **100%**; repeat leaks < **5%/quarter** on your grid.

8.4 Drone sentries: heat, dose, and perimeter

Mission sets

- **Dose mapping:** rotary UAV + NaI/LaBr₃; 30–60 m AGL raster; **MDA by cell** meets spec; K-40 vs Cs-137 separation.
- **Thermal sentry:** dawn/dusk roof scan for hot spots, smolders, PV anomalies.
- **Perimeter watch:** IR + visible; geofence breach beacons; **no facial ID**—empty island, you watch for animals and anomalies.

Cadence

- **Dose:** daily primaries, weekly secondaries; surge after storms.
- **Thermal:** daily at dawn; fire weather = every 4 h.

Triggers to ground

- Wind > 10–12 m/s; dose rate > design; link loss tiers (hold → roost → RTH).

KPIs

- Map refresh (primaries) $\geq 95\%$ / 24 h; hotspot closure time ≤ 6 h.
 - False positive rate (change-detect) < 5%.
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8.5 Quarry & materials strip (when you must take rock, sand, water)

Use: trench bedding, concrete patch, berm upkeep; never for vanity.

Fleet & tools

- **Tracked loader:** low-shear bucket, on-tool HEPA shroud.
- **Screener:** vibratory with enclosure; ΔP monitored.
- **Water cart:** RO rinse of haul marks; curb socks at washdown.

Doctrine

- Micro-quarries only: **single face**, lee side, **daily cap** on tonnage.
- Keep haul routes inside your hygiene network; every load passes **wash pad** and **gamma gate**.

KPIs

- Visible dust = **0** beyond 20 m downwind; Δ PM at intake **no increase** vs baseline during ops.
-

8.6 Scheduling & autonomy

Policy

- **Night downslope window (02:00–06:00):** heavy sweeping, PV wash, intake mound service.
- **Trade-wind noon:** loud jobs (CIP, load-bank, quarry brief).
- **Kona mode:** outdoor work throttled; switch to indoor mitigations; protect intakes (double prefilters).

Autonomy tiers

- Route-follow → supervised → adaptive; crisp teleop triggers: edge proximity, Δ P spike, unknown object class, wind gusts, dose excursion.
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8.7 Comms, nav, and beacons

- **Comms:** multi-radio (sub-GHz mesh + LTE-private + 5 GHz); link-loss state machine (hold → safe park → RTH).
 - **Nav:** GNSS + visual SLAM; QR curb tags at corners; **micro-geofences** around intakes and edges.
 - **Beacons:** dirty cones with RFID; portable **shield pucks** mark dose finds; all beacons expire (time-bomb) to force review.
-

8.8 Decon, custody, and evidence

- **Every exterior crossing** hits **wash train** (air-knife → RO mist → squeegee → portal).
- **Passports:** photo sets, Δ P traces, torque curves, spectra URLs; object-level IDs on clamps, filters, totes.
- **Chain-of-custody:** fines to pan → waste lock → filter press → **drum** with barcode; quarry loads: weigh → wash → receipt.

8.9 Failure modes & drills

- **Wind spike mid-route:** autonomous pause; edge “roost”; resume when gusts < limit.
- **HEPA head clog:** ΔP red; swap cassette; mark route segment “amber”; rerun after wash.
- **Dose anomaly:** stop, back 3 m; drop shield puck; alert; schedule **shield-and-cut** or bury.
- **Thermal alarm (roof):** dispatch foam drone; roof mule vac perimeter; PV isolate string; confirm with IR.

Drills

- Monthly: link-loss, wind-gust, dose-excursion tabletop; **storm playbook** twice a year.

8.10 Numbers to design by (quick table)

Task	Cadence	Thresholds / Notes
Intake corridor sweep	Daily	PM $\downarrow$ $\geq 40\%$ vs baseline; grate dwell ≥ 8 s
Roof vacuum	Weekly (storm-eves extra)	Wind < 8 m/s; ΔP -guided passes
Gutter purge	Monthly (storm-eves)	Downspout flow = 100%
PV wash	1–3 $\times$ /mo	EC < 40 $\mu\text{S}/\text{cm}$; no soaps
UAV dose raster	Daily primaries	MDA per cell $\leq$ target; wind < 10–12 m/s
Utility valve PM	Quarterly	Torque curves logged 100%
Leak clamp	As needed	Acoustic drop ≥ 10 dB; torque pattern pass
Quarry pull	As needed	Zero visible dust beyond 20 m

8.11 Lived exterior: what it looks/sounds like

You don’t see much. Low silhouettes, dull finishes, quiet wheels. At dawn a drone sketches the compound’s shadow; at noon a sweeper noses a curb; at dusk a crawler disappears into a gutter slot. Evidence is the soundtrack: the soft thrum of a vac head, a single grate clank, the roosting beep of a UAV. The outside world is reduced to **perimeter, pathway, quarry**—and even those are temporary, because the only permanent thing out there is the wind.

Bottom line: Keep the intakes clean, roofs cold, valves obedient, and maps fresh. Do it with robots that are quiet, measurable, and easy to wash. The exterior is not a neighborhood anymore; it's a life-support surface—maintained to spec, then left alone.

9) Labor, Class, and Containment

9.1 Architecture of separation: the air tree and where people live

- **Air tree topology:** the main habitat sits at the **top of the pressure cascade**; **staff bunkers** branch **downstream** (lower ΔP , separate AHUs), with **one-way wash/airlock** back toward work zones only.
- **Physical plan:** staff galleries parallel to mechanical spines (wash train, RO, battery), **no sightlines** to family courts; **sound breaks** (labyrinth corridors) to prevent overheard life.
- **Logistics:** dining, laundry, and recreation duplicated; **no shared kitchens**; tool rooms and time clocks at the staff side of pressure doors.

Rule: Air is class. The duct map is the org chart.

9.2 Identity, credentials, and movement

- **Biometric access tiers:** palm/vein + PIN; **color code** matches air tree—Gold (owners), Blue (clinical/ops leads), Gray (tech staff), Red (waste/dirty side).
- **Movement graph:** directed edges ($\rightarrow$) from staff bunkers $\rightarrow$ work zones $\rightarrow$ decon $\rightarrow$ bunkers. **No edges** to family wings; emergency override is logged and reviewed.
- **Escort protocol:** any cross-class contact (clinic, arbitration) occurs in **neutral rooms** with **counter-flow ventilation** and dual doors.

Audit fields

who, badge_tier, gate_id, dir(in/out), ts, reason(code), escort_id?, override(bool), video_ref

9.3 Work-credit ledgers (the economy that replaces cash)

- **Unit: Work Credit (WC)**—1 WC $\approx$ 1 hour baseline, modulated by hardship/skill multipliers (0.7–1.8 $\times$).

- **Earning:** task finish + QA pass emits WC; rework debits. Night/dirty shifts carry multipliers.
- **Spending:** private time slots (gym, VR, craft), choice menus, library reservations, extra bandwidth, festival rations.
- **Floors & caps:** living minimum = **40 WC/week**; hoarding discouraged via decay (−1%/week over 4 weeks idle).
- **Treasury:** the “Food & Filters Board” can place **surtaxes** (e.g., +5 WC/week) during scarcity to fund spares or membranes.

Ledger schema

acct_id, role, week, wc_earned, wc_spent, multipliers{night,dirty,critical}, decay, balance, notes

9.4 NDAs as constitutions

- **Scope:** operations, locations of intakes/outfalls, inventory levels, medical events, arbitration records.
 - **Form:** perpetual, inheritable; violations classified by **risk to uptime**.
 - **Sanctions palette:** WC fines → duty reassignments → **containment** (restricted movement) → **exile** (see 9.10).
 - **Counterweight:** **sealed dissent channel** to a three-person council (owner rep, clinic chief, ops chief) with **retaliation immunity** if the claim is sustained.
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9.5 Roles, ranks, and rotations

- **Core roles:**
 - **Ops Tech (Gray):** wash train, RO, batteries, air tree.
 - **Exterior Teleop:** sweepers, roof/gutter, utility clamps.
 - **Waste Crew (Red):** press, drums, yard.
 - **Kitchen & Hydro:** prep, grow, harvest, clean.
 - **Clinic Aides:** vitals, sterilization, pharmacy.
 - **Guardians:** perimeter console, beacon management, incident logging.

- **Rotation doctrine:** 6-week cycles; no one holds **dirty** or **night** more than **2 cycles/quarter** unless voluntarily (with multipliers).
- **Cross-qual:** every role shadows one tier adjacent (e.g., Hydro ↔ Kitchen, Ops Tech ↔ Teleop).

Roster block (example)

person_id, role_primary, role_secondary, cycle_id, shifts[...], night_count, dirty_count, wc_multiplier_avg

9.6 Reward & morale instruments

- **Rations & menus:** choice nights tied to WC; festival lots (coffee, cocoa) unlocked by total-squad safety streaks (e.g., 30 days without portal alarm).
 - **Room upgrades:** small privacy improvements (curtains, light scenes, storage) purchasable with WC.
 - **Learning & media:** skill modules and restricted books/software unlocked by WC + certification.
 - **Rites:** quarterly “Green Day” when air, water, and power metrics all green → extra heat for showers, long music block in the gallery.
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9.7 Oversight, grievance, and justice

- **Court of First Resort: Arbitration Bench** (clinic chief + ops chief + rotating lay member) meets **twice weekly**; rules codified; decisions logged and posted (names masked).
 - **Evidence standard:** Job Logs, gate trails, camera clips with privacy masks, WC ledgers; **hearsay discounted**.
 - **Appeal:** one appeal to a **sealed panel** (owner + two lay reps).
 - **Anti-capture:** rotation of lay reps; clinic holds veto on punishments that threaten health.
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9.8 Health, fatigue, and containment ethics

- **Shift limits:** max **10 h** tasking, **50 h/week**; nights limited; dirty tasks split into **90-minute** bouts with air & water breaks.

- **Clinician authority:** heat stress, dermatitis, or respiratory flags **auto-pull** workers from Red tasks; WC cannot override medical orders.
 - **Psych hygiene:** mandatory decompression—15 min light/quiet after waste or death tasks; private counseling hours in WC.
 - **Pregnancy/parenthood:** reassignment away from Red; additional WC floor to cover rest.
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9.9 Information, rumor, and speech

- **Bulletin: Daily State** (air/water/power/food/waste) posted; **no inventory numbers** beyond what crews need.
 - **Rumor valve:** weekly council Q&A in the gallery; anonymous question drop with answers published.
 - **Forbidden speech:** intake/outfall coordinates; codes; schedules for exterior runs; medical specifics (except to clinicians).
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9.10 Exile in a place with nowhere to go

- **Triggers:** sabotage, repeat NDA breach with intent, violence beyond self-defense.
 - **Procedure:** three-step review (bench → sealed panel → owner sign-off). Clinic must attest the person can physically survive.
 - **Execution: exile kit** (water, rations, radio, thermal, med basics) + **geofence unlock** to a non-return perimeter gate; all credentials revoked.
 - **Alternatives: deep containment** (windowless micro-suite, no network, escorted work only) reviewed every 30 days.
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9.11 Succession & mutiny scenarios

- **Key ceremonies:** quarterly quorum drill; sealed envelopes with fallback codes; 2-of-3 key shards needed to alter air/water setpoints or open vaults.
- **Owner incapacitation:** ops chief + clinic chief become interim sovereigns; after **30 days**, a **compact** (written) is ratified by **supermajority ($\geq \frac{3}{4}$)** of adult residents.

- **Mutiny:** any attempt to seize the air tree or battery rooms is classed as existential—guards shift to **fail-closed** posture; non-lethal suppression where possible; arbitration resumes once rooms are secure.

9.12 Training & certification (class as curriculum)

- **Onboarding (staff):** 40 h—air/water doctrine, waste discipline, teleop basics, NDA scope, grievance path.
- **Red tasks license:** 16 h hygiene + 16 h decon + 8 h yard practice; annual renewal with error drills.
- **Teleop license:** 8 h sim + 4 h live under supervision; six-month recert.
- **Cross-class civics:** one seminar per quarter where Gold and Gray share a table (without air mixing)—ritualized but necessary.

9.13 Metrics that actually move class boundaries

- **WC Gini Index:** inequality in credits; rising Gini triggers **festival release** or **surtax relief**.
- **Dirty/Night load parity:** variation < **20%** across staff after rotations.
- **Gate violations:** per-capita unauthorized crossings; **target = 0**; any spike forces door logic review.
- **Clinic pulls:** rate of health-driven task reassignments; above baseline → equipment or cadence fix, not worker blame.
- **Grievance latency:** median days to decision (goal ≤ **7**).

9.14 Records & schemas (because memory equals legitimacy)

person_id, tier, bunk_id, certifications[], medical_flags[], nda_signed_ts,
wc_balance, wc_earn/spend history[], night_dirty_counts, grievances[status],
discipline_history[], last_rotation_ts

Data hygiene: append-only; hash-chained daily; masked views for non-owners; clinic controls medical fields.

9.15 Lived texture (what it feels like)

The staff wing wakes earlier, the air a little heavier, the corridors tighter. Breakfast is faster, doors hiss more often, and the day is measured in **ΔP dips, torque curves, and drum weights**. The ledger light over each bunk—green, amber, red—says how many credits are left for a movie, a long shower, a private hour. At the end of shift there's a wash, a count, and—if the day was good—a small choice that feels like freedom: a sweeter tea, a longer song, a thicker curtain.

Bottom line: In a sealed Maui with almost no outside world, class is engineered: in ducts, doors, ledgers, and rules. It can be made tolerable by rotation, grievance, and small freedoms—or it can harden into a quiet prison. The structure you set at the air tree becomes the society you live in.

10) Security Doctrine in an Empty Country

10.1 First principles (no audience, no theatrics)

- **Uptime over glory.** The mission is continuity—air, water, power, food—not “winning” encounters.
- **Low signature, high certainty.** You prevent contact by being hard to notice and easy to verify from inside.
- **One-way accountability.** Every security action leaves an internal audit trail; nothing leaks outward.

10.2 Perimeter architecture: deny quietly

- **Geofenced shells.** Concentric, software-defined boundaries snapped to terrain. Outer rings are wide “notice zones;” inner rings are **hard stops** around intakes, pump houses, wash pads.
- **Passive shaping.** Berms, ditches, and rock gardens that steer paths away from sensitive doors without looking like fortifications.
- **RF fencing (non-aggressive).** Low-power field sensing along approach corridors to spot powered objects and anomalous transmissions; logs go to a sealed console, not to sirens.

- **Decoy intakes & vents.** Dead-end snorkels and dummy hatches placed where a curious path would naturally lead; they waste time and signal intent without exposing the real core.
 - **Light & sound discipline.** No skyline glow, no tonal machine signatures; loud or bright tasks run only in pre-set “masking windows” (e.g., trade-wind noon).
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10.3 Aerial hygiene: detect, don’t duel

- **Anti-drone umbrellas.** Layered measures that start with **visibility denial** (camouflage, heat muffling) and progress to **geofence warnings** and **route-of-least-interest** beacons that nudge overflight paths away.
 - **Sentries in the sky.** House drones fly quiet patterns for **change detection** (new tire tracks, heat anomalies, disturbed berms) and dose/thermal mapping. They do not chase; they mark and notify.
 - **Roof sovereignty.** Gutter crawlers and roof mules keep surfaces clean to avoid thermal hot spots that read like beacons.
-

10.4 Ground beacons & trip lines: detect without drama

- **Intrusion beacons.** Low-profile ground nodes that sense pressure, vibration, or magnetic disturbance; they report *pattern* (pace, weight class), not identity.
 - **Disposable markers.** When a beacon fires, a robot drops a **time-limited marker** (cone, dye tag, or “shield puck”) so the event is reviewable in daylight and then disappears on schedule.
 - **Evidence, not engagement.** The only autonomic actions are recording, routing robots away, and preparing a sealed work ticket.
-

10.5 Doors, airlocks, and decoys: control crossings

- **Goods & waste locks only.** No “people doors” to the exterior. Locks are monodirectional and slow; every cycle creates a passport (photos, times, gamma/chem checks).
- **Decoy routines.** Scheduled “maintenance” at dummy sites keeps patterns noisy; real service runs are jittered in time and route so no single path becomes canonical.

- **Air doctrine.** Pressure always favors the interior. If a lock misbehaves, it fails closed and the wing behind it isolates.
-

10.6 Incident playbooks (secrecy and uptime first)

All playbooks share three moves: *pause the vulnerable system; gather evidence from standoff; restore minimum function.* Investigation waits.

- **Perimeter touch (footprints, moved rock, beacon hit).**
 1. **Uptime:** throttle fresh air; switch to recirc for the nearest wing.
 2. **Evidence:** pre-planned drone orbit at safe height; ground mule snaps orthogonal photos; drop a time-limited marker.
 3. **Restore:** re-grade berm/rock garden overnight; re-baseline beacons; reopen air at 02:00–06:00 window.
- **Sky anomaly (low overflight or hovering object).**
 1. **Uptime:** shift to **silent mode** (fuel cell + low fans); hold outdoor jobs.
 2. **Evidence:** thermal + visible capture, no pursuit.
 3. **Restore:** stagger restarts; purge media of any diagnostic signals that could fingerprint equipment.
- **Utility tamper (valve box opened, conduit disturbed).**
 1. **Uptime:** isolate branch; provide alternate feed (tank, battery).
 2. **Evidence:** sealed photos; torque curve of current valve state; chloride/soil quick tests logged.
 3. **Restore:** replace lids with sacrificial decoys; reset true lid with new signature stamp.
- **Dose hotspot appears where none was.**
 1. **Uptime:** re-route outdoor paths; close nearby locks.
 2. **Evidence:** UAV gamma raster; place shield puck; no digging.
 3. **Restore:** deploy temporary shield wall; schedule **shield-and-cut** under separate work order.

10.7 Command & control: who sees what

- **Single glass, two levels.** Operators see **events and mitigations**; owners see **trends and risks**. Raw media is sealed; only hashes and thumbnails ride the daily digest.
 - **Write-once logs.** Every alert spawns an append-only record with time, coordinates, sensors, actions, and who acknowledged.
 - **Red team cadence.** Quarterly scripted breaches to exercise beacons, locks, and the *pause-gather-restore* rhythm.
-

10.8 Human factors: calm is a security layer

- **No sirens.** Security “sounds” are indoor light cues and short text on the mission board; adrenaline spikes burn judgment.
 - **Clear boundaries.** Staff know **never** to pursue or confront; the doctrine forbids heroics.
 - **Debriefs, not rumors.** After any event, a 5-minute briefing explains *what changed* (routes, schedules), not speculation about *who*.
-

10.9 Metrics that matter

- **Mean time to safe posture (MTSP):** from alert to paused/recirc or silent mode.
 - **Exposure avoided:** outdoor job minutes preempted vs scheduled during alerts.
 - **False-positive burden:** operator minutes spent on non-events; must trend down without reducing detection.
 - **Signature index:** proxy score of visual/thermal/RF quietness (lower is better).
 - **Leak rate:** number of events with any exterior artifact left behind unintentionally (target: 0).
-

10.10 Failure modes & graceful degradation

- **Sensor drift/blindness.** Rotate calibrations; favor **pattern change** over fixed thresholds; if blind, widen stand-off and shorten outdoor windows.
- **Comms loss.** Pre-agreed behaviors: drones roost, mules stop, locks freeze; the bunker defaults to safe posture until heartbeat returns.

- **Pattern lock-in (predictable routes).** Automated route randomizer with guardrails; detect repeated path reuse and alarm.
 - **Decoy compromise.** Retire and rebuild elsewhere; never “repair” a blown decoy.
-

10.11 Ethics in a vacuum

With no neighbors to warn and no state to report to, the only check on excess is self-discipline: **minimum force, maximum distance, record everything, forget nothing.** The system refuses fights and prefers dust and time to do the work. If the bunker survives, it will be because it learned to be **uninteresting** to the outside and **predictable** to itself.

Bottom line: In an empty country, security is civil engineering plus choreography: shape the land, quiet the machines, sense the unusual, and practice the same three moves—**pause, record, restore**—until they happen without drama.

11) Clinic, Apothecary, and Mortuary

11.1 Facility plan: quiet rooms for loud problems

- **Zoning by pressure:** OR/Procedure (+40–50 Pa), Treatment/Pharmacy (+35 Pa), Ward (+25 Pa), Sterile Core (+40 Pa), Soiled Utility (0→–10 Pa to dirty stack).
 - **Rooms that matter:** one **minor OR** with laminar canopy; **procedure bay** (blocks, reductions, dressings); **two-bed observation** with oxygen and suction; **isolation room** with independent AHU; **sterile core** (autoclave, pack table); **pharmacy/compounding** alcove; **quiet room** (family, palliative).
 - **Power & gases:** battery-backed circuits, manifolded O₂/N₂O or O₂ concentrator bank, medical vacuum with bacterial filters.
 - **Infection control:** single-direction instrument flow (soiled → decon → pack → sterilize → sterile store → point of use). No backflow ever.
-

11.2 Anesthesia and analgesia under scarcity

Goal: keep people safe enough to repair and recover while preserving agents for the next patient.

- **Rationing ladder (principle, not dosage):**
 1. **Local & regional first** (nerve blocks, field infiltration) + non-opioid multimodal analgesia.
 2. **Conscious sedation** for short procedures with monitored airway; **oxygen & capnography** mandatory when available.
 3. **General anesthesia** only for life/limb; prioritize agents with long shelf life and simple scavenging.
- **Airway doctrine:** bag–valve mask competence for all clinic staff; supraglottic devices before advanced airways except when clearly indicated.
- **Ventilation:** manual/portable ventilator with HEPA on exhaust; low fresh-gas flows to reduce agent burn; never compromise scavenging for conservation.
- **Consumable discipline:** color-coded circuits; filters dated/rotated; leak checks logged; oxygen budget tile on the clinic board.

Metrics

- Unplanned airway escalation (target **0**), reversal use rate (low), agent-days remaining (trend), post-op hypoxia events (zero tolerance).

11.3 Antibiotic stewardship when there is no truck tomorrow

North star: narrow, short, evidence-led; protect last-line agents like a crown.

- **Decision tree (conceptual):**
 - **Watchful waiting** for likely viral/self-limited presentations with safety-net checks.
 - **Source control** (drain, debride, remove) before/with antibiotics.
 - **Empiric to targeted:** collect cultures whenever feasible; de-escalate within 48–72 h based on clinical course or basic lab surrogates.
 - **Sequence before escalation:** rotate within class before jumping classes to preserve diversity.
- **Pharmacy tiers:**
 - **Tier A (workhorse):** broad but older agents with known stability; used for common, non-severe infections.

- **Tier B (reserve):** for failed A or defined indications.
- **Tier C (last-resort):** locked inventory; **two-signature** release.
- **Infection prevention first:** hand hygiene supplies; vaccine chest (if on hand) prioritized to wound management and tetanus; decolonization only when indicated.

Metrics

- “Days of therapy per 100 bed-days,” culture capture rate, de-escalation within window, stockout risk index.

11.4 Sterilization, decontamination, and reuse standards

- **Hierarchy: Steam** (autoclave) whenever material allows → **dry heat** for metal items → **low-temperature** for heat-sensitive (validated chemical systems) → **single-use** where safety demands.
- **Instrument sets:** mini-sets tuned to bunker surgery (wound, minor ortho, dental, OB basics) to shorten cycle times.
- **Tracking:** set ID → case ID → patient ID; indicator tapes & biological spore tests on schedule; “sterile shelf life = event-related,” not time-only.
- **PPE reuse:** only if design supports it; otherwise launderables + face shields; never compromise the **clean/dirty corridor** rule.

11.5 Fluids & electrolytes without a warehouse

- **RO to cell:** process RO polished for **parenteral-compatible** rinse/clean—not for compounding sterile IVs unless validated.
- **Oral first:** priority on oral rehydration, enteral feeds, and slow correction strategies; **clinic policy over recipes** to avoid dangerous home brews.
- **IV triage:** reserve limited sterile solutions for shock, anesthesia support, and dialysis; track bag-days like fuel.

Metrics

- Oral vs IV hydration ratio, IV bag-days remaining, electrolyte complication rate.
-

11.6 Improvised renal replacement (dialysis) when choices are few

- **Triage reality:** not everyone can be dialyzed indefinitely. Transparent criteria protect staff from ad-hoc injustice.
- **Peritoneal preference:** if any sterile supply chain remains, **peritoneal dialysis (PD)** is less power- and pump-intensive than hemodialysis; still requires strict asepsis and trained hands.
- **Hemodialysis fallback:** only with validated water quality and robust disinfection; power and filter budgets must be explicit on the **Power & Water Boards**.
- **Palliative pivot:** when membranes, fluids, or access fail—**comfort-first renal care** (edema management, symptom control, honest counseling).

Dashboards

- “Dialysis viability clock”: dialysate days, filter hours, access complications, nurse-hours per week.
-

11.7 Chronic care without refills

- **Diabetes:** glucose monitoring cadence, foot checks, diet planning; ration fast-acting agents for procedures and emergencies.
 - **Hypertension & heart failure:** salt/water stewardship aligned with pantry; slow titration; clinic walk-test as a crude functional metric.
 - **Mental health:** protected counseling hours; light therapy slots; quiet room etiquette; **no abrupt discontinuations** without review.
-

11.8 The Apothecary: compounding, stability, audit

- **Core bench:** scale, mortar, capsule machine, sterile hood (if available), labeler; **beyond-use dating** policy based on stability data where known.
- **Compounding lanes (examples):** topical antiseptics, pediatric dilutions, simple analgesic blends, electrolyte supplements for enteral use.
- **Stability doctrine:** amber glass, desiccants, cool dark store; lot folders with assay notes when possible; **quarantine shelf** for doubtful stock.

- **Security:** two-key cabinet for controlled/abusable agents; **discreet inventory** (need-to-know).

Ledger (apothecary)

prep_id, formula_ref, lot_in[], qty_out, beyond_use_date, maker_id, verifier_id, storage_zone, notes

11.9 Palliative medicine as a first-class service

- **Triggers:** metastatic disease, end-stage organ failure, refractory infection, catastrophic injury with non-survivable prognosis.
- **Elements:** symptom control (pain, breathlessness, anxiety, nausea, secretions), family presence protocols, spiritual/ritual accommodation.
- **Environment: Quiet Room** with soft light scenes, low fan noise, and pressure integrity; visiting hours that respect containment.
- **Documentation:** goals-of-care conversation recorded; comfort-med bundles pre-packed to reduce decision friction in crisis.

Metrics

- Uncontrolled symptom episodes, late goals-of-care discussions (target: fewer), family satisfaction notes.
-

11.10 Records, triage, and ethics

- **Triage board:** color-coded (Immediate / Urgent / Delayed / Palliative) with **review times**; decisions are **signed and time-bounded**.
 - **Clinic log (append-only):** patient pseudo-ID, complaint, vitals, zone, actions, materials consumed, adverse events, follow-up date.
 - **Ethics rounds:** weekly 30 min review of tough calls (dialysis rationing, last-line antibiotic releases, palliative transitions) with clinic + two lay observers.
 - **Privacy:** redact names on public summaries; maintain sealed originals with clinic custody.
-

11.11 Death underground: mortuary, memory, and hygiene

- **Pronouncement & ID:** two-clinician check; tag with **name, pseudo-ID, time, cause (provisional), effects inventory**; photograph with consent policy honored.
- **Care of the body:** wash, shroud, and **cool** (cold room or evaporative sled) within hours; infectious cases follow enhanced precautions; **no aerosolizing** procedures.
- **Rites:** a short, repeated ritual the community understands—music, words, a reading—scheduled to avoid crossing work shifts; a **Place of Names** in the gallery with etched plaques.
- **Disposition (context-dependent):** sealed niche in cooled ossuary, or deep entombment in marked, mapped ground away from intakes and waterworks; **map and log** every site.
- **Effects & records:** inventory sealed; will/succession protocol executed; **grief rota** (coverage for close coworkers for 24–48 h).

Mortuary ledger

decedent_id, time_of_death, cause_est, handling_precautions, custody_chain[],
disposition(type, location, map_ref), effects_log_url, next_of_kin_or_proxy

11.12 Operations cadence (clinic)

Daily

- Triage huddles (AM/PM), oxygen/agent clocks, sterilizer BI indicator check, pharmacy temperature log, waste pass-through count.

Weekly

- Antibiotic review (active cases), anesthesia circuit inspection, palliative case conference, dialysis viability check, stock rotation.

Monthly

- Code drill, instrument set audit, apothecary reconciliation, mortuary cold-room maintenance, ethics round extended.
-

11.13 Numbers to design by (quick table)

Element	Target	Rationale
OR overpressure	+40–50 Pa	Keep bioburden out
Isolation ACH	12–15	Airborne control
O ₂ autonomy	≥ 72 h critical	Concentrator + cylinders
Sterile sets	≥ 3× daily need	One in use, one cooling, one ready
Antibiotic “last-line” stock	Locked, 90-day horizon	Two-signature access
Cold storage (mortuary)	2–4 °C	Hygiene & dignity
Palliative room noise	< 35 dBA	Calm as care

11.14 Lived medicine: how it feels

Clinics in the old world were about choice; this one is about **sequence and witness**. The hiss of oxygen, the click of a pressure door, the autoclave’s thump—metronomes for a place that saves what it can, eases what it can’t, and writes everything down. The apothecary smells faintly of alcohol and paper; the mortuary is cool, labeled, and kind. Scarcity doesn’t excuse cruelty; it demands **clarity**.

Bottom line: Medicine after the fall is logistics wrapped in ethics. Anesthesia becomes strategy, antibiotics a currency, dialysis a clock, and palliative care a promise. The clinic keeps people alive; the apothecary makes the most of what’s left; the mortuary ensures the living can go on.

12) Culture, Time, and Sanity

12.1 Culture as infrastructure (rotate it like crops)

- **Stacks, not trophies.** Treat **libraries, instruments, theaters, and gyms** as **rotating crops**: scheduled, measured, refreshed. Each has a curator, a maintenance slot, and a “yield” target (hours used, pieces performed, pages read, km rowed).
- **Circulation plans.**

- **Library:** quarterly **theme rotations** (craft, history, field medicine, fiction). 10–15% of shelves go to “fresh pick” carts; worn copies rebound in the shop, not discarded.
- **Instruments:** 4–6 week “residencies” for small ensembles; practice rooms on WC reservations; sound bleed checked monthly.
- **Theater:** two alternating formats—**quiet cinema** (headset-only, <35 dBA) and **live floor** (speech/music with sound ceiling).
- **Gym:** periodized programs (strength, cardio, mobility) rotated every 6–8 weeks; low-impact days aligned to **power budget**.
- **Conservation:** every cultural space has an **energy budget** (lux-hours, kWh), **noise ceiling**, and **cleaning plan** (dust is the enemy of violins and lungs).

KPI “yields” (weekly targets)

- Library: **≥ 6 reading hours/person**; new loans **≥ 1.5/books/person**.
- Instruments: **≥ 90 min practice/person** or **1 group session**.
- Theater: **2 screenings + 1 live event** per week.
- Gym: **150–300 min** mixed activity/person.

12.2 Light, clocks, and the body (circadian as policy)

- **Wing clocks:** each wing runs a **24 h light program** with **dawn (6500 K → 4000 K)**, **day (4000 K)**, **dusk (3500 → 2700 K)**, and **night (amber footlights)**.
- **Shift protection:** night-shift galleries slide their clock **+8 h**; **blue-light lockouts** 2 h before sleep zones.
- **Seasonal scripts:** 6-week “seasons” (Wet/Dry/Trade/Kona) alter color temperature, cloud drift cadence, and sound masks to punctuate time.
- **Clinical hooks:** SAD-risk residents get **high-lux morning niches**; insomnia protocol bundles light, temperature, and breath work before meds.

Metrics

- Sleep diary compliance **≥ 80%**; reported sleep latency **< 25 min** median; midday sleepiness scale trending ↓.

12.3 Ritual calendars (predictability beats novelty)

- **Daily:**
 - **First Light (07:00):** gallery sky brightens; 90 s of shared stillness.
 - **Midshift Bell (13:00):** 3-tone chime; posture & water break.
 - **Last Light (20:30):** lights warm; quiet hours begin; instrument practice ends.
- **Weekly:**
 - **Hands Night:** communal craft/repair (sew, bind, oil tools) with low music.
 - **Story Seat:** one person tells a true story; 20 min cap; no recording.
 - **Feast/Lean Pair:** one **feast** (morale lots unlocked) and one **lean** (simple fare, low energy) to give rhythm and gratitude.
- **Quarterly:**
 - **Green Day:** if air/water/power all green $\geq 21/28$ days, extended showers + concert.
 - **Remembrance:** read names, unveil plaques, 3 min silence—see §11 for mortuary flow.

Rule: rituals are optional, **but always available**; predictability is the point.

12.4 Boredom as a systems risk (detect and treat)

- **Early indicators:** rising **minor conflicts**, WC hoarding without spend, **screen-time spikes**, skipped meals, decline in library loans.
- **Counters:**
 - **New frictions, not new stuff:** change **constraints** (time trials in gym, 2-week chamber music focus, recipe challenges), not inventories.
 - **Micro-quests:** skill trees (woodworking badge → instrument maintenance → luthier assist).
 - **Rotation of ownership:** rotate curation roles; let different hands run theater week, gym cycles, or the herb wall.

- **Red flags & responses:**
 - **Rumor heat** up → 10 min **town note** with facts only.
 - **Sleep drift** → enforce light discipline + post-dinner dim.
 - **Conflict cluster** → pause overlapping shifts; swap partners; add counselor hours.

Dashboard hooks

- “Culture Load” tile: loans, practice hours, event attendance, gym minutes, **quiet-hours violations**. Triggers auto-open **program tweaks** (e.g., add duet hours, shift film night).
-

12.5 Etiquette for silence and celebration

- **Quiet hours: 21:00–06:30; < 35 dBA** in galleries, headsets for cinema; doors soft-close; carts foam-tired.
 - **Practice hours:** instruments **08:00–20:00** in rooms only; percussion on **pad days** unless performance night.
 - **Celebration corridor:** designate one wing bay as **loud-permitted** (up to **70 dBA** 2 h/week) with **door cushions**, sound traps, and a **posted schedule**.
 - **Food etiquette:** feasts leave nothing sticky; **wipe & sweep** before the bell; clinks yes, clangs no.
 - **Grief & quiet:** when a death is declared, **signal light** at gallery narthex; mark 24 h of softer scenes and voices; normal work continues, but ambience bends.
-

12.6 Spaces that work (and stay clean)

- **Library:** closed stacks for fragile items; **page shields** and nitrile at the desk; dehumidification steady 45–50% RH.
- **Practice rooms:** floating floors, wall traps, glass porthole; CO₂ sensor drives vent; **slots** bookable in 30–60 min blocks.
- **Theater:** retractable risers; headset splitter rail for quiet cinema; projector and amps on **clean power**; filters vacuumed weekly.
- **Gym:** rubber where it counts; **no chalk**; wipe protocols; rowers and bikes with **mechanical meters** (no cloud).

- **Makerspace (clean craft):** dust extraction to carbon/HEPA; no aerosols; wood finishes waterborne only.
-

12.7 Media, memory, and taste

- **Library curation:** 60/30/10 mix: **practical** (repair, medicine, ag), **nourish** (literature, art, history), **joy** (comics, cookbooks, children's).
 - **Music & film:** local archives prioritized; **perform what you store**—monthly “record to room” where stored pieces are played live.
 - **Food & culture:** weekly menu card includes a **line of provenance** (why this herb, who taught this recipe); feast days pull a **memory dish** from someone's past.
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12.8 Roles & rotations (who keeps culture green)

- **Curators:** Library (catalog + repair), Music (tuning + programs), Theater (A/V + schedule), Gym (program + maintenance).
 - **Rotation:** 8–12 weeks; apprentice shadow model; **handover checklist** (inventory, faults, next plan).
 - **WC ties:** curation earns WC; attendance earns less—**making** outranks **consuming**.
-

12.9 Safety & hygiene (because culture sheds dust too)

- **Noise dose:** track with wearable badges for musicians and crew; enforce **rest ears** days.
 - **Infection:** wind instruments on **mouthpiece-only sharing** with sterilization; headset pads laundered; mats wiped after use.
 - **Fire:** theater drapes M1-rated; no open flame rituals; candles = **LED only**.
-

12.10 Numbers to design by (quick table)

Element	Target	Why
Quiet-hours ambient	< 35 dBA	Sleep & nerves
Library RH	45–50%	Book & instrument health
Practice room CO ₂	< 1000 ppm	Focus & safety
Light scenes/day	≥ 3 (dawn/day/dusk)	Timekeeping
Culture time	≥ 7 h/person·wk	Sanity floor
Gym time	150–300 min/person·wk	Health floor
Event cadence	3/wk	Predictability

12.11 Lived texture: how time moves underground

Morning slides in on the ceiling like sky on a slow dimmer. The library smells clean and faintly of glue; someone tunes a violin two doors down; a rower ticks quietly in the gym. After work, the theater glows just enough for hands to find seats. On feast nights the gallery hums, and on grief nights the lights go soft and people walk slower. The calendar is a promise that tomorrow won't be the same as today—even if the weather never changes.

Bottom line: Culture is not garnish; it's **life-support for minds**. Rotate it, meter it, and ritualize it like you do air and water. Boredom corrodes seals and tempers; good clocks, good books, and shared songs keep the bunker from turning on its people.

13) Governance of the Few

13.1 Forms that rule: trusts as governments

- **Entity of record:** a **perpetual trust** holds land, plant, and inventories. Beneficiaries = lineage members; **protectors** = ops chief + clinic chief (veto over moves that endanger uptime or health).
- **Operating arm:** a **Facilities Company** (FacCo) licensed by the trust to run air/water/power/food/waste/security. FacCo can be replaced for cause by a 2-of-3 protector vote.

- **Civic stand-ins:** *Boards* that map to systems, not ideologies: **Air/Water Board, Power Board, Food & Filters Board, Security Board, Ethics Bench**. Each board has: 1 owner seat, 1 operator seat, 1 rotating staff seat. Quorum = any 2.
- **Budget language:** every decision cites a **resource ledger** (days of filters, kWh, membranes, drums). Motions that don't bind to a ledger are out of order.

Charter snippet (starter clauses)

The Trust shall prioritize continuity of life-support over wealth preservation. Protectors may nullify distributions that impair stock of filters, membranes, or medicines below 90-day floors.

13.2 Keys, ceremonies, and quorum masks

- **Key hierarchy:**
 - **Level-0 (L0) Genesis:** cold shards in three sealed caches (clinic safe, battery room vault, off-site cache); needed only after catastrophic lockout.
 - **Level-1 (L1) Governance keys:** 2-of-3 to change setpoints on air/water/power or to open sealed stores (last-line antibiotics, fuel). Holders: owner rep, ops chief, clinic chief.
 - **Level-2 (L2) Routine keys:** rotate monthly for door maps, inventory release above thresholds, schedule overrides; held by on-call leads.
- **Ceremony cadence:**
 - **Monthly:** L2 rotation with checklist (revocations verified, seals inspected, hash signed).
 - **Quarterly: Quorum drill**—simulate loss of one L1 holder; remaining two reconstitute access within 10 minutes.
 - **Annually:** L0 **dry run** reading (no open), ensure caches present, tamper seals intact.
- **Quorum masks:** when a key ceremony runs, operators wear **quorum masks**—identical aprons and face shields—to reduce social pressure and personal attribution in video logs. Actions are attributed to **roles**, not faces.

Audit lines

event_id, level(L0/L1/L2), holders_present[], start_ts, stop_ts, controls_changed[],
evidence_urls[], seal_hashes[], anomalies

13.3 Succession drills & incapacitation rules

- **Triggering events:** death, disappearance, prolonged incapacity (>72 h), declared conflict of interest that threatens uptime.
 - **Playbook: “Three Chairs”**
 1. **Stabilize systems:** freeze nonessential setpoint changes for 24 h; clinic verifies no medical coercion.
 2. **Designate interim:** ops chief + clinic chief jointly appoint an interim owner-rep for ≤ 30 days.
 3. **Convene Charter Review:** within 7 days, a written compact defining powers, floors (filters, meds), and veto scope.
 4. **Ratify:** supermajority ($\geq \frac{2}{3}$) of adults, secret ballot in the gallery; *quorum = 80% present*.
 - **Heir conflict:** if multiple heirs assert standing, **Ethics Bench** hears only procedural claims (eligibility per charter); operations remain under interim compact until ratification.
-

13.4 Courts without outsiders: adjudication when the judge and owner share a table

- **Ethics Bench composition:** clinic chief (chair), ops chief, rotating staff assessor (drawn by lot). Owner attends without vote unless serving as ops or clinic chief (discouraged).
- **Jurisdiction:** rationing disputes (dialysis, last-line antibiotics), discipline above WC fines, NDA breaches, exile/containment (\$9.10).
- **Process (7-day clock):**
 - **Day 0:** filing & case number; notify parties; preserve logs (Job Logs, gate trails, camera clips).
 - **Day 1–3:** submissions; sealed interviews; clinic may order cooling-off or duty changes.

- **Day 4–5:** hearing in **neutral room** (counter-flow ventilation, two doors).
- **Day 6:** written decision with **resource impact statement** (“membranes affected,” “oxygen duty,” “drum yard delta”).
- **Day 7:** optional **appeal to Sealed Panel** (owner + two lay reps) on *procedure only*.
- **Sentencing palette:** WC debits/credits; duty reassignments; education and re-cert; containment (time-bound); exile (only with clinic attestation).
- **Transparency:** publish **anonymized decisions** on the Mission Board with rationale and metrics.

13.5 Policy by playbook: decisions bind to procedures

- **Required playbooks:** *Air Budget Shift, Water Scarcity, Silent Mode, Kona Gloom, Filter Rationing, Dialysis Triage, Last-Line Antibiotic Release, Exile Procedure, Succession Loss.*
- **Structure:** trigger → authority (which board + keys) → steps → success criteria → rollback.
- **Versioning:** semantic version numbers; only L1 quorum can bump major version; minor versions via board majority.

Example header: “Last-Line Antibiotic Release v1.2”

Trigger: culture-confirmed pathogen susceptible only to Tier C || septic shock with Tier A/B failure.

Authority: Ethics Bench + L1 quorum (2-of-3).

Steps: source control → consent → dosing plan → daily review.

Success: clinical improvement in 48–72h; de-escalation possible.

Rollback: lock cabinet; log remaining doses; post-case review in 7 days.

13.6 Maintenance disputes as mutiny (and how to defuse)

Mutinies don’t announce themselves; they appear as “maintenance” arguments—filters “accidentally” misplaced, setpoints “optimistically” nudged, “temporary” bypasses left in place.

- **Signals:** unexplained ΔP trends, repeated “test” overrides, gate propping, ledger hoarding, anonymous notes about “hoarded comfort.”

- **Counter-mutiny doctrine:**
 - **Separate people from valves.** Lock routine setpoints behind L2; require **two-person presence** for bypasses; red-tag anything left overnight.
 - **Flood the logs with daylight.** Publish a **Change Sheet** daily: all overrides, who, why, duration, rollback.
 - **Offer a policy venue.** Create **Compact Summits**—timed sessions for proposing new floors (e.g., showers, heat) tied to resource math.
 - **Rotate high-friction tasks.** If “the same five people” hold the air tree at night, build a second crew.

Drill: quarterly “**Bypass Hunt**”—operators and staff sweep for abandoned changes; WC bounty for finds.

13.7 Rationing, floors, and vetoes (who can say no)

- **Hard floors (cannot be crossed without L1):** filters ≥ 90 days, membranes ≥ 60 days, antibiotics Tier B ≥ 60 days, diesel/ H_2 ≥ 7 days critical, potable storage ≥ 48 h.
 - **Soft floors (board authority):** gym hours, feast lots, hot-water minutes, cinema watt-hours.
 - **Clinic veto:** any decision that plausibly degrades safety/health (air changes, water quality, work/rest) can be paused 72 h pending Bench review.
 - **Ops veto:** any order that raises risk of plant damage beyond recovery timelines can be paused 24 h pending Board review.
-

13.8 Records that make power legible

- **Daily State (posted):** green/amber/red for air, water, power, food, waste; notes of any active playbook; quorum actions since yesterday.
 - **Append-only ledgers:** WC, keys, changes, drums, pharmacy, dialysis. Hash-chained; printed weekly and sealed in **Gallery Box**.
 - **Sealed archives:** unredacted logs on WORM media in clinic custody; opened only by L1 quorum with Bench present.
-

13.9 Roles & conflicts (keep hats separate)

- **Owner-as-operator risk:** owner may not chair the Ethics Bench or sign both sides of a contract with FacCo.
 - **Dual-hat cooling-off:** any person acting as both owner rep and board voter must abstain on sanctions or resource floors that materially benefit their bunk.
 - **Clinic independence:** clinic chief's employment is by the Trust, not FacCo; removal requires L1 quorum and Bench concurrence.
-

13.10 Elections without parties (and with tiny electorates)

- **Who votes:** adults cleared for Blue wings; staff in Red may vote by sealed card via clinic courier.
 - **What's elected:** rotating staff seats on boards; lay member on Bench; culture curators (§12.8).
 - **Cadence:** 12-week terms, staggering so not all seats flip together.
 - **Ballot:** paper slips with role icons; counted in gallery under two cameras; results posted with hashes.
-

13.11 Metrics that keep governance honest

- **Decision latency:** median days from motion to decision (goal ≤ 7).
 - **Override half-life:** % of overrides rolled back within 24 h (goal $\geq 95\%$).
 - **Floor breaches:** count/year (goal 0); if breached, publish root cause and corrective action.
 - **Equity of hardship:** variance in night/dirty cycles across staff (goal $< 20\%$, see §9).
 - **Appeal rate & reversals:** % of Bench decisions appealed and % reversed (watch for capture or drift).
 - **Key drill success:** time to reconstitute L1 with one holder absent (goal ≤ 10 min).
-

13.12 Failure modes & graceful degradation

- **Key capture:** a holder refuses ceremonies → invoke **Protector Bypass** (clinic + ops generate emergency L1 with L0 reference; original keys revoked).
 - **Bench capture:** repeated biased rulings → **Mass Challenge** ($\frac{2}{3}$ signatories force external auditor...which you don't have). Fallback: rotate two new lay assessors; clinic retains veto meanwhile.
 - **Owner coup:** unilateral setpoint changes → **Trip Guard** (hardware interlock that requires 2-of-3 contact within 60 s or reverts).
 - **Paper drift:** charters/readmes diverge from practice → **Blackout Drill** (24 h operate under printed playbooks only; rewrite where gaps appear).
-

13.13 Lived legitimacy: how it feels when it works

Key ceremonies are dull, decisions arrive on time, the Daily State is readable, and no one is surprised by a rationing call because the floors were posted weeks ago. Arguments happen, but they point at numbers and playbooks, not faces. When a death arrives, the masks come off, the Bench sits in the Quiet Room, and the ruling reads like a logbook, not a verdict. In a vault with few people and fewer exits, **legitimacy is logistics with signatures**.

Bottom line: In an empty country, governance shrinks to *who holds the keys, how they are used, and who can stop them*. Trusts stand in for states, boards for councils, and playbooks for laws. If you bind power to procedures and procedures to resources, the bunker remains governable—even when the only voters can share a table.

14) Procurement Without Markets

14.1 Principles (operate like a submarine machine shop)

- **Reverse the supply chain:** everything is a parts bank first, a product second.
 - **Prefer compatibility over performance:** converge on few connector families, fasteners, bearings, seals, and voltages.
 - **Document entropy:** every downgrade or cannibalization updates drawings, spares lists, and SOPs. If it's not logged, it won't repeat.
-

14.2 Cannibalization trees (robots, membranes, vehicles)

A) Robots (UGV/UAV/manipulators)

- **Families:** standardize on 2 UGV chassis, 1 quadrotor class, 1 crawler, 1 manipulator wrist.
- **Priority salvage order:**
 1. **Sensors:** cameras (global-shutter first), IMUs, LiDAR APDs/SiPMs, RTKs.
 2. **Actuation:** BLDCs with encoders, harmonic drives, cycloid boxes, linear rails.
 3. **Power:** ESCs, DC/DCs, battery BMS boards, contactors.
 4. **Structure:** carbon tubes, brackets, fasteners (A2/A4), cable carriers.
- **Substitution map:** quad ESC → UGV aux motor (derated); UAV gimbal motor → small valve actuator; UGV inverter fan → cabinet fan.
- **“Organ donor” tag:** any hull with ≥ 3 critical faults becomes a donor; strip to bare frame within 48 h to stop part rot.

B) Membranes (RO & MBR)

- **RO (8" elements):** keep **first-stage** housings freshest; down-cascade older elements to **second-stage** or low-demand skids; last life as **brine prefilter** (sacrificial).
- **MBR cassettes:** panel-swap before full-cassette swap; worst panels reserved for **graywater**; cracked headers → parts donors.
- **Rules:** never mix ages in same pressure vessel; normalization curves updated after every rotation.

C) Vehicles (service carts & gensets)

- **Rotate engines/motors:** healthy alternator → hospital genset spare; starter motors and injectors pooled.
 - **Tire policy:** identical sizes for carts/UGVs where possible; cut slicks into floor mats.
 - **Fuel system donors:** filters, hoses, quick disconnects harvested on day of retirement; tanks rinsed and repurposed as gray headers.
-

14.3 The sacrificial inventory (what you burn to save the core)

- **Definition:** pre-named stock that exists to be consumed during spikes (Kona gloom, ashfall, outbreak), so critical assets remain green.
 - **Classes:**
 - **Air:** extra MERV frames, carbon drawers (galley/latrine only), HEPA row “Z”.
 - **Water:** one RO train’s first-stage elements + extra antiscalant.
 - **Power:** diesel/H₂ for **7 days** of clinic/air-spine; one inverter stack.
 - **Food:** morale lots + 14 days of noodles/rice/oil/salt for “lean week.”
 - **Activation:** only by L1 quorum (§13.2) tied to a named playbook (e.g., **Kona Gloom**).
 - **Rebuild rule:** first procurement task after a surge is to restore sacrificial levels before any upgrades.
-

14.4 Parts bank & ledgers (reverse-BOM as law)

Item record (minimum fields)

part_id, category(robot/pump/RO/MBR/vehicle/HVAC/electrical),
form_factor, fit_notes, donor_id?, hours_on_part, pass_fail_tests[],
location(bin,row), qty, last_test_ts, next_test_due, alt_uses[], retire_by

Reverse-BOM (example: HEPA head UGV)

UGV_HEPA_HEAD v2.1

- └─ Motor BLDC 48V 750W (ALT: drone motor 5010 @ 36V derated)
- └─ ESC 60A 48V (ALT: UAV ESC 50A + fan)
- └─ Impeller 180mm PA6 (PRINTABLE: yes; hub steel)
- └─ ΔP sensor 0–2 kPa (ALT: HVAC 0–2.5 kPa)
- └─ Gasket EPDM 6x20 (CUT: sheet EPDM stock)
- └─ Fasteners M6 A4 (POOL)

KPIs

- Part reuse rate $\geq 30\%$ by count; donor strip time ≤ 48 h; bin accuracy $\geq 98\%$; “unknowns on shelf” = 0.
-

14.5 Salvage operations (quarry, wreck, yard)

- **Survey first:** dose/chem scan, photos, tag the lot.
 - **Cut plan:** tools, cuts, containment (tarps, vacs), tote IDs, return path.
 - **Strip hierarchy:** remove **small, high-value, low-contamination** first (electronics, valves), then medium (motors, pumps), then structure.
 - **Decon on return:** wash train $\rightarrow$ bench test $\rightarrow$ assign **grade A/B/C** (A ready, B needs work, C donor).
 - **Log:** each tote weighs in and out; salvage time charged to part ids.
-

14.6 Repair standards & derating

- **Stamp repairs:** heat-shrink color bands: **green** (meets spec), **amber** (derated), **red** (donor only).
 - **Derating rules:**
 - Electronics run at $\leq 70\%$ nameplate; add heatsinks; validate with 2-hour burn.
 - Pumps at $\leq 80\%$ head; confirm NPSH with margin.
 - Gaskets from sheet stock get **service-life halved** unless proven.
 - **Test sheets:** pass/fail with amperage, temp rise, vibration, ΔP ; QR links to video.
-

14.7 Craft reskilling tracks (people become the supply)

A) Machinist (metal & plastics)

- **Tools:** mini-lathe, small mill, drill press, bandsaw, grinders, arbor press; 3D printer (nylon/PC), filament dryer.
- **Stock:** 6061, 316L, 4140, POM, PTFE, UHMW; metric fasteners; key stock; spring pins.

- **Skills (ladder):** turning bushings → boring housings → cutting gears → TIG basics → pump shaft remake.
- **Cert targets:** bearing fit (H7/g6) within $\pm 10 \mu\text{m}$; surface finish $Ra \leq 1.6 \mu\text{m}$ for seals.

B) Brewer (sanitation & bioprocess)

- **Role:** produce sanitizer (ethanol/acidified water), vinegars, yeasts; run small anaerobic/MBR adjuncts.
- **Kit:** conicals (15–60 L), hydrometers, pH/EC meters, plate filter, pasteurizer.
- **Outputs:** 70% ethanol sanitizer; peracetic acid make (careful); food ferments; pH buffers.
- **SOP anchors:** CIP loops, sterility checks, colony counts; **no aerosols**.

C) Glasser (borosilicate & seals)

- **Role:** repair sight glasses, labware; pull capillaries; form small flow cells and lamp chimneys.
- **Kit:** bench torch, annealing kiln, marver, graphite blocks, diamond files.
- **Skills:** seal-to-metal with graded seals; simple joints; anneal schedules; stress-check with polarized film.
- **Outputs:** flow cells for sensors, dip tubes, lamp shields, ampoules for drug splits.

D) Medic (biomed tech + clinic assistant)

- **Role:** maintain concentrators, suction pumps, monitors, defibs; assist sterilization; fabricate simple splints.
- **Kit:** multimeter, oscilloscope, leak tester, spare O-rings, filters, suction jars.
- **Skills:** NIBP calibration, sensor recell, valve rebuild, autoclave gasket swap, oxygen purity tests.
- **Metrics:** uptime $\geq 95\%$ for critical devices; PM logs 100%.

Cross-skills: soldering, conformal coat repair, gasket cutting, crimping, swaging, safety wire, thread repair.

14.8 Make-versus-take matrix

Need	Make (in-house)	Take (salvage)	Rule
Gaskets, shims	Sheet stock + die	—	Always make
Impellers, small gears	Print + machine hub	Wreck pumps	Make for fit, take for material
Bearings, seals	—	Strip from donors	Take; standardize sizes
Housings, brackets	Machine/weld	Take if perfect	Make if geometry simple
PCBs, sensors	Rework only	Strip & test	Take; keep donor boards dry
Pressure vessels	—	—	Never improvise

14.9 Spares policy (floors)

- **Fasteners:** M4–M12 A4; > **200 of each length** in range.
 - **Seals:** O-ring kits NBR/EPDM/Viton; sizes for pumps/valves on list.
 - **Bearings:** common 6xxx/7xxx sizes with 2–3 sets per active pump/UGV.
 - **Motors/ESCs:** 10% hot spares by fleet count.
 - **Membranes:** RO first-stage set **+50%** panels for MBR.
 - **Electrodes:** pH/EC/DO 2-deep per instrument; dry spares stored per vendor spec.
 - **Filtration:** prefilters 90 days; HEPA row; carbon drawers for 90 days of galley/latrine.
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14.10 Workflows (who does what, when)

Daily

- Donor strip tickets; bench tests; parts bank updates; “Make Queue” review.

Weekly

- Reverse-BOM audit; bin cycle counts (10%/wk); salvage recon walk; machine tool PM.

Monthly

- Skill boards check (badges advanced); spares floor review; sacrificial inventory drill.

Quarterly

- Full “Blackout Shop” trial: fabricate one critical assembly from banked parts only; document gaps → update floors.
-

14.11 Metrics that keep you honest

- **Bank health:** days of operation supported by parts bank for top 10 failure modes.
 - **Cannibal yield:** % of donors fully stripped within 48 h.
 - **Lead-time zero:** % of repairs completed without waiting on external supply (goal $\geq 90\%$).
 - **Skill coverage:** number of residents certified in each craft (floor: **2 per craft**).
 - **Sacrificial integrity:** time to restore sacrificial levels after activation (goal ≤ 14 days).
-

14.12 Failure modes & hedges

- **Counterfeit drift (mis-labeled parts):** barcode + photo on receipt; bench test everything; “unknown” box purged monthly.
 - **Skill single-point:** two-deep rule; apprentice always shadowing; **video SOPs** on WORM.
 - **Tool outage:** keep manual fallbacks (hand taps, analog gauges, mechanical meters).
 - **Salvage contamination:** pre-wash in field; bag smalls; run yard wash before bench.
-

14.13 Lived practice

You stop asking “where do we buy this?” and start asking “**what can become this?**” A drone dies, and three valves live. A cracked RO element becomes a brine prefilter. A violin string becomes a safety wire. The shop wall fills with reverse-BOMs and pencil notes, and the pride shifts from **new** to **enough**.

Bottom line: Without markets, procurement is memory plus craft. Name the sacrificial stock, keep the parts bank true, and train hands that can turn scrap into uptime.

15) Failure Cascades & Triage

15.1 Principles (how to think when everything leans)

- **Protect life-support clocks first:** *air* → *water* → *power* → *waste* → *food* → *culture*.
 - **Collapse early, not late:** shutter the least essential wings **before** the core begins to wobble.
 - **Decision trees, not debates:** every cascade has a named playbook with triggers, authorities, and rollbacks.
 - **One-way logs:** actions are append-only; postmortems fix playbooks, not memories.
-

15.2 Water cascade (membrane → rationing → hygiene disease)

Trigger ladder (examples):

- $SDI_{15} > 3$ for > 24 h → **pretreat surge** (DAF on, recovery ↓).
- $RO \Delta P$ slope $> 1.5 \times$ baseline OR permeate cond $\uparrow 30\%$ → **CIP** + rotate elements.
- Two trains down OR brine dilution $<$ setpoint → **Water Scarcity v2.x**.

Water Scarcity v2.x (decision tree):

IF storage < 48 h @ current draw:

- 1) Halt non-critical Blue (dishwashers, luxury taps)
- 2) Shift showers → 48 h cadence; 3 min caps
- 3) Hydroponics: pause fruiting feed; Leafy EC ↓ 10%; photoperiod -2 h
- 4) RAS: reduce feed 30%; O2 priority; partial purge only
- 5) Kitchen: menu to low-wash prep; single-pot days
- 6) Clinic: IV use review; oral-first mandate
- 7) Board meets: authorize sacrificial RO train if needed

Rollback when storage ≥ 72 h AND permeate cond within spec 48 h

Hard floors: potable ≥ 48 h, clinic Blue ≥ 72 h, process RO ≥ 24 h.

Common failure coupling: water cuts raise **airborne** risk (less cleaning) → coordinate with Air Budget.

15.3 Air cascade (prefilter burn → HEPA pinch → ΔP failure)

Trigger ladder:

- Prefilter burn > 2× plan OR Kona dust forecast → **Filter Rationing v1.x**.
- H14 ΔP ≥ 2× new OR pinhole fail → **bank isolate** + rotate duty.
- Clinic ΔP < +30 Pa OR wing ΔP step < 5 Pa → **Wing Close v1.1**.

Filter Rationing v1.x (decision tree):

IF prefilter stock < 30 d OR HEPA bank at 1.8× ΔP:

- 1) Close least-used culture/office wing (purge, seal, 0.5 ACH)
- 2) Drop MERV-11 stage; double G4 area; ACH –10% low-occupancy
- 3) Carbon restricted to clinic/residential; galley tight-hob rules
- 4) OA to 02:00–06:00 window only during dust events
- 5) Announce odor etiquette; enforce door sweep maintenance

Rollback after 7 clean days + media audit ≥ 60 d

Hard floors: clinic +40–50 Pa, residential +25–35 Pa, purge ≤ 10 min to 10–12 ACH.

Coupling: less OA → more **VOC** load on carbon; coordinate with Kitchen and Clinic.

15.4 Power cascade (battery fault → blackout → thermal drift)

Trigger ladder:

- SoC < 24 h @ forecast load OR week-long Kona gloom → **Silent Mode v2.x**.
- Inverter stack fail → **Bus Split v1.0** (clean/dirty separation).
- Battery room H₂ alarm → chargers trip; **Energy Triage**.

Silent Mode v2.x (decision tree):

IF PV forecast < load for 48 h:

- 1) Load-shed Ladder to Level 4 (laundry/dish heat OFF, hydro lights rotate)
- 2) Swap clinic/air spine to fuel cell; genset 2–3 h/day for RO + bulk charge
- 3) HVAC widen setpoints ±2 °C; night fan cap

4) Freeze noncritical charging (UGVs, recreational)

5) Announce quiet window; reschedule loud work to trade-wind noon

Rollback when SoC ≥ 36 h + PV > load 24 h

Hard floors: clinic/air spine uninterrupted, cold storage stable, RO daily minimum met.

Coupling: power cuts $\rightarrow$ **water** (RO) & **food** (hydro lights) degradation $\rightarrow$ pre-plan menu & irrigation downgrades.

15.5 Food cascade (LED outage $\rightarrow$ yield slump $\rightarrow$ protein gap)

Trigger ladder:

- Hydro PPFD outage > 20% bays OR EC/pH drift persistent $\rightarrow$ **Crop Reset/Rotate**.
- RAS O₂ excursion OR feed stockout < 30 d $\rightarrow$ **Protein Substitution** (BSF/cricket uplift, fish weekly $\rightarrow$ biweekly).
- Pantry class < 90 d floor $\rightarrow$ **Lean Week** (activate sacrificial noodles/oil/salt).

Food Triage (decision tree):

IF harvest < 70% target for 2 weeks:

- 1) Shift to Leafy-heavy menus; fruiting cut 30–50%
- 2) Mushrooms +20% throughput (add racks, UVB D-boost)
- 3) Insect protein +50% in blends (pasta, patties)
- 4) Pantry: release legumes; enforce soak/pressure protocols (low energy)
- 5) Festival lots held; announce morale substitutes (spice rotations)

Rollback after 3 consecutive weeks $\geq 90\%$ harvest target

Coupling: low cooking power days pair with **wet/simple** menus to spare fans & carbon.

15.6 Waste cascade (MBR TMP run-away $\rightarrow$ yard swell $\rightarrow$ odor)

Trigger ladder:

- TMP slope > threshold or flux collapse $\rightarrow$ **MBR Clean v1.2** + **Water Scarcity** cross-call.

- Yard occupancy > 85% slots OR leak → **Yard Drought** (suspend noncritical press; packaging compaction).
- Odor event → raise exh ACH, carbon swap, deep clean.

Waste Triage (decision tree):

IF MBR off ≥ 12 h:

- 1) EQ tank buffer + 24 h timer
- 2) Ration Black flows (toilet intervals, kitchen scrape discipline)
- 3) Divert Gray to Purple only; suspend hydro blowdowns
- 4) Start emergency chemical clarifier (if stocked)

Rollback after flux stable 48 h + yard < 70% capacity

15.7 Compound cascades (the nasty ones)

- **Kona + Ashfall Week:** Air (OA clamp) + Water (SDI spike) + Power (PV slump).
Response bundle: Silent Mode L4 + Filter Rationing Amber + Water Scarcity + Menu to “quiet, low-wash.”
- **Hot-room Clinical Cluster:** Water (hygiene $\uparrow$) + Waste (bioload $\uparrow$) + Air (ΔP margin $\downarrow$).
Response: Close one residential wing to free media; elevate clinic ΔP +5 Pa; switch to disposables where safe; Yard surge plan.

15.8 Shuttering wings (how to close a room without breaking a home)

Wing Close v1.1 (checklist):

1. Post notice (08:00) + reassign bunks/work zones.
2. Purge to dirty stack 10–12 ACH, 10 min; wipe high-touch.
3. Bag loose textiles; move perishables; seal drains.
4. Door gaskets check; ΔP to 0.5 ACH recirc only.
5. Update maps, routes, lighting; reopen only after **two clean days** + media audit.

Selection heuristic: close **farther from clinics**, **lower ΔP** wings first; keep **light courts** balanced across remaining living areas.

15.9 Culling programs (what stops when)

- **First to pause:** cinema amps, laundry heat, fruiting tier expansion, PV wash frequency, gym power machines (rowers/bikes stay).
- **Second:** workshop heavy tools, culture “loud bay,” instrument residency rotation.
- **Third (only under L1):** one gallery’s HVAC to setback, one PV quadrant wash defer, noncritical teleop windows.

Rule: never cull **clinic, air spine, dialysis (if active), RO minimums, waste press.**

15.10 Social contract redrawn (temporary compacts)

When floors are at risk, governance posts a **72-hour Compact**: what’s paused, who decides, when it rolls back, and what metrics end it. The Compact requires **two signatures (ops + clinic)** and a Daily State tile showing the counters (e.g., *Membrane days*, *SoC hours*, *Drum slots*). If a Compact extends beyond **7 days**, an open forum is mandatory; beyond **21 days**, a ratification vote triggers.

15.11 Operator dashboards (what you actually watch)

- **Air Budget:** ΔP slopes, prefilter days, H14 duty A/B, carbon breakthrough.
 - **Water Budget:** storage hours, RO recovery/ ΔP , SDI, brine dilution.
 - **Power Budget:** SoC hours, PV forecast, load-shed level, quiet window.
 - **Food Budget:** kg harvest vs target, RAS DO min, pantry floors.
 - **Waste Budget:** TMP slope, yard % full, odor index.
 - **Risk Tile:** active playbooks, next triggers in each ladder, time since last wing close.
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15.12 Example cascade timelines (illustrative)

Day 0 (Kona + ashfall forecast)

- 06:00: Activate **Filter Rationing (Amber)**, **Silent Mode L2**; reschedule outdoor work.
- 10:00: **Water Scarcity** pre-stage; DAF warm.
- 20:30: OA window set to 02:00–06:00 only.

Day 1

- SDI spikes to 5 → Recovery 30%; one RO train in CIP.
- SoC forecast 22 h → Load-shed to L3; hydro lights rotate.
- Menu shift: stew day; low-wash.

Day 2

- H14 ΔP row at 1.8× → close Culture Wing E; ΔP margin restored.
- Yard at 80% → Waste Drought: packaging compaction; press schedule halved.

Day 3

- Wind eases; SDI 2.7 → open OA window to 4 h; RO recovery 40%.
- Rollback planning; feast lots remain locked.

Day 4 (rollback)

- Restore L2 loads; reopen Wing E after wipe/purge; announce one festival hour.

15.13 Numbers to design by (summary floors)

System	Floor	Trip
Air clinic ΔP	+40–50 Pa	+35 Pa sustained
Potable storage	≥ 48 h	< 36 h
SoC autonomy	≥ 24–36 h	< 18 h
Yard capacity	< 85%	≥ 85%
Pantry class	≥ 90 d each	< 60 d
Hydro harvest	≥ 90% target	< 70% 2 wks

15.14 Drills & postmortems

- **Quarterly Blackout Drill:** 12 h on batteries + fuel cell; verify ladders and quiet scenes.
- **Dust/Kona Tabletop:** 90 min; walk triggers, comms, wing close.

- **After-Action (within 72 h):** what tripped, what worked, update playbooks, restock **sacrificial inventory** first.
-

15.15 Lived texture (what it feels like)

Cascades don't arrive like explosions; they arrive like **checklists**. Lights warm, fans dim, a wing sighs shut, and the menu card swaps to soups and pickles. The gallery board shows three tiles in amber and a clock counting up from the decision. People follow the rituals because the rituals kept them alive last time. Then the wind turns, the counters climb back above the floors, and the vault exhales.

Bottom line: Catastrophe is a slope, not a cliff. Name the slopes, fix the ladders, close what you can spare, and keep the clocks you can't. If you redraw the social contract with clarity and floors, you can ride a bad week without breaking the bunker.

16) Endgames

16.1 Re-emergence (when the island breathes again)

Greenlight criteria (all must hold for ≥ 12 consecutive months):

- **Ambient dose:** $\leq 0.2 \mu\text{Sv/h}$ (backgroundish) at noon shade; $\leq 0.3 \mu\text{Sv/h}$ worst 95th percentile on primaries.
- **Soil & dust:** Cs-137 $< 100 \text{ Bq/kg}$ in top 5 cm across intake corridors; Sr-90 in forage $< 75 \text{ Bq/kg}$.
- **Water:** raw surface sources within potable pretreat bounds (turbidity $< 5 \text{ NTU}$, no persistent organics above trigger list).
- **Food chain sentinels:** leafy greens under film + mushrooms test below internal release thresholds for 6 harvests.

Phased plan (90–360 days):

1. **Phase 0 (Prep):** map “green lanes,” cache decon pods, issue **Re-entry Kits** (P3 respirator, dosimeter, wipes, sealable bags).
2. **Phase 1 (Survey):** daylight-only egress on **tethered routes**; exterior sleeping still banned; double-bag all finds.

3. **Phase 2 (Habitation):** open **dayhouses** (air-washed sheds) with HEPA; cook/eat still indoors; roofs/gutters restored.
4. **Phase 3 (Outdoor cooking & sleep trials):** pilot with **dose-ticket** logs; abort if weekly rolling average rises > 30%.
5. **Phase 4 (Stand-down):** remove decoy intakes; collapse to normal filtration; declare **Air & Water Floors** as civic (posted, not secret).

Governance flips:

- Boards shift from **rationing** to **codes** (roof cleaning, gutter discipline, shared intake corridors).
- Drum yard becomes **archive & museum**, not only storage.

16.2 Diaspora by sea (sealed cargo, short hops, long bets)

Mission: leave Maui alive, intact, and untracked; arrive able to make water and air day-1.

Vessel profiles:

- **Work cat (10–14 m):** diesel-electric, low draft, shieldable cockpit, **sealed holds** for totes & drums; PV awnings.
- **Aux sailer (11–13 m):** silent passage, desal day tank, kite option; emergency only—sail training mandatory.
- **Support barge (modular):** slow, towed; carries **RO skid**, fuel, drums, spare batteries; scuppers baffled.

Cargo doctrine (ranked):

1. **Life-support stack:** compact RO + IX, HEPA/Carbon media, portable fans, gaskets, test kits.
2. **Food & seed:** high-germ seed vault, yeast bank, dried staples, micronutrient blends.
3. **Power:** foldable PV, controller, LiFePO₄ blocks, small fuel cell + 5–15 kg H₂.
4. **Tools & spares:** bearings, seals, fasteners, printers, meds, optics, radios.
5. **Culture:** archives subset, instruments, children's materials.

Navigation & comms:

- **EMCON windows:** AIS dark except collision risk; burst satcom at pre-dawn with rotating keys.
- **Waypoints:** unpeopled coves every **60–120 nm**; intake galleries test; no discharges near reefs.
- **Fuel:** biodiesel day tank + polish loop; log **grams/knot-mile**.

Departure checklist (48 h):

- Dose map → hull wash → HEPA purge → load in clean lock → seal manifests (hash + print) → cast off at night slack tide.

Arrivals:

- **Quarantine protocol:** 72 h in roadstead; air & water self-contained; drone surveys shore; land only after three clean kits (soil/water/air) pass.

16.3 Drone trade (thin threads between distant vaults)

Use case: swap small, dense value (membranes, meds, optics, seeds, data) at **radial 200–800 km** without people.

Airframes & lanes:

- **VTOL lift + fixed-wing cruise** (10–25 kg payload; 400–1,000 km max still air).
- **Wave-riding canister** for sea ditch options; floats + dye beacon.

Protocol:

- **Escrow beacons:** each enclave maintains a **neutral pad** with one-way lockers; trade occurs locker-to-locker with **hash-verified manifests**.
- **Two-envelope cargo:** inner sterile pod (tamper-evident), outer sacrificial shell (washable).
- **Windowing:** depart within 30-min weather/dose windows; receiver publishes **GREEN LIGHT** token to a public bulletin channel; no bilateral chatter.

Trust & fraud control:

- **Serial reciprocity:** first 3 trades are **asymmetric goodwill** (low risk items) to establish honesty.

- **Witness hashes:** each enclave posts daily Merkle roots of job logs; trades reference a dated root for non-repudiation.
- **Quarantine:** open pods in negative room; culture/assay before integration.

Failure handling:

- **Divert or ditch:** on weather/dose spike, divert to secondary pad; if fuel/battery uncertain, ditch in pre-declared sea box.
- **Loss ledger:** every failed flight logged; three failures in 90 days → session pause & renegotiation.

16.4 The archival end (sealing the vaults, writing forward)

If wind, membranes, heirs, or luck fail, end well.

What to preserve (three rings):

1. **Ring A – How to Live:** air/water/power playbooks, cultivation/germplasm, medicine basics, toolmaking, governance.
2. **Ring B – Who We Were:** names, languages, music, art, recipes, children’s stories, maps before/after.
3. **Ring C – How to Rebuild:** geology, soils, hydrology, metallurgy, chemistry primers, reverse-BOMs, material tables.

Media & redundancy:

- **Stone & steel:** etched stainless plates for indexes; rock-cut “tablets” for Rosetta summaries; avoid paints/inks.
- **Paper:** rag paper in sealed, dehumidified chests; print hash on every page.
- **Digital:** WORM optical + flash (triplicate); checksummed; open formats (UTF-8, PDF/A, FLAC, PNG).
- **Placement: three vaults**—main, counter-slope, sea-cave; each with independent air-brick and rockfall protection.

Sealing rite (48 h):

- Final “State of the House” ledger printed & signed; filters & membranes counted; names read; vaults closed with **mechanical locks** + time letters.

- Last act is **teaching**: a recorded class walking through the plates and books, addressed to a reader who may not share our tools or tongue.

16.5 Choosing an endgame (decision matrix)

Condition	Re-emerge	Sea diaspora	Drone trade	Archival end
Dose falling, water local	Yes (Phase 1–4)	Optional	Yes	Keep live
Dose steady, supplies low	Risky	Likely	Maybe	Prepare
Distant signals heard	Cautious	Maybe	Yes	Parallel
Leadership fractured	Hard	Dangerous	Unreliable	Safest
Membranes/filters < 60 d	No	Yes	Maybe	Yes

Authority: L1 quorum + Ethics Bench; **72-hour Compact** posted with rollback metrics.

16.6 Numbers to design by (endgame floors)

Element	Floor / Target
Ambient dose to reopen lanes	$\leq 0.2 \mu\text{Sv/h}$ (12-mo avg)
Soil Cs-137 (intakes/paths)	< 100 Bq/kg
Drone payload/range	10–25 kg / 400–1,000 km
Sea kit autonomy	14–21 days self-contained
Archive redundancy	3 sites , 3 media types
Quarantine (arrivals)	72 h negative room

16.7 Lived texture: four endings

- **Re-emergence:** doors open at dawn; air feels thick and unscented; someone laughs at nothing in particular. The first kettle boiled outdoors tastes like victory.

- **Diaspora:** the dock is quiet work—straps checked, hatches dogged, a hand on a shoulder longer than usual; the sea smells clean and enormous.
- **Drone trade:** a speck becomes a shadow; a locker clicks; the ledger light turns green; somewhere, someone just exhaled.
- **Archival end:** plates stacked, lids sealed, a last sweep of the floor. The gallery is still; the only sound is a pen scratching a name into the Book of Rooms.

Bottom line: Endings are logistics with vows. Whether you step out, set sail, trade by air, or close the lids, pick an endgame on numbers—not nerves—and leave a map for whoever finds the door next.

You said:

Expand: Appendix: The Clock Inventory What actually governs survivability horizons: filters by square meter, RO pressure vessels, spare bearings, lithium cells, antibiotics, anesthetics, seed stock, and fiction.

Appendix: The Clock Inventory

What actually governs survivability horizons: filters by square meter, RO pressure vessels, spare bearings, lithium cells, antibiotics, anesthetics, seed stock, and fiction.

A.1 Why “clock inventory” matters

Not all shortages are equal. Some items **stop time** (HEPA square meters, RO pressure vessels, lithium cells). Others **bend time** (antibiotics, anesthetics, seed stock, bearings, fiction). This appendix defines **floors**, **burn equations**, and **audit schemas** so the community sees the true horizon.

A.2 Master ledger (schema)

item_id, family(air/water/power/waste/food/clinic/culture/tools),
form(unit), qty_onhand, location, condition(A/B/C), floor_min,
burn_rate(unit/day), horizon_days = qty_onhand / burn_rate,
tests_due[], last_move_ts, notes

A.3 Air: filters & carbon (the first clock)

A.3.1 Floors & units

- **Prefilters (G4/MERV 11/13):** store as **m² of face media** by stage.
Floor: 90 days at **Amber** mode.
- **HEPA H14 cassettes:** store as **m² of absolute media** and **complete rack rows**.
Floor: one full **spare row** per live rack + 60 days burn.
- **Carbon drawers (clinic/galley/latrine):** **kg of GAC** by grade.
Floor: 90 days at normal odor load.

A.3.2 Burn math (daily)

prefilter_burn_m2 = (OA_hours/24) * (dust_index) * (door_cycles_factor) * stage_factor

HEPA_burn_m2 = prefilter_burn_m2 / ladder_efficiency (empirical slope)

carbon_burn_kg = VOC_load_grams / adsorption_capacity (g/kg) * safety_factor(1.2–1.5)

A.3.3 Audit

- **Daily:** ΔP slope per stage; breakthrough sniff/TVOC delta on carbon.
 - **Weekly:** pinhole scan one HEPA row (rotate).
 - **Horizon tile:** HEPA_days, Prefilter_days, Carbon_days.
-

A.4 Water: RO membranes, housings, IX resin

A.4.1 Floors

- **SWRO elements (8"):** $\geq$ one first-stage train + 50% of second-stage count.
- **Pressure vessels (8" FRP):** 1 spare per 8 in service (storm/impact insurance).
- **Cartridge filters (5 μm):** 60 days at SDI=3; 30 days surge kit.
- **IX resin:** bed volumes for 90 days polish.

A.4.2 Burn math

$$\text{membrane_burn_elements/day} = \text{CIP_frequency} * (\text{elements_per_CIP_reject_rate})$$
$$+ \text{failure_popouts/week} / 7$$

$$\text{cartridge_burn} = (\text{pretreat_SDI} * \text{m3_feed}) / (\text{cartridge_capacity_SDI_units})$$

$$\text{IX_burn_bv/day} = \text{m3_polish} / \text{bed_volume}$$

A.4.3 Tests

- Normalized permeate flow (NPF), salt passage, ΔP slope; tracer dilution @ diffuser quarterly.

A.4.4 Horizon tile

- Membrane_days, Vessel_spares_count, Cartridge_days, IX_BV_days.
-

A.5 Power: lithium cells, inverters, fuel

A.5.1 Floors

- **LiFePO₄ modules:** $\geq$ 1 full inverter stack's worth + 10% of remaining fleet.
- **Inverter modules:** 1 hot spare stack (N+1).

- **Diesel/H₂: 7 critical days** (clinic + air spine + RO minimum).
- **H₂ sensors & fans: 2-deep** spares (a failed fan can cost a room).

A.5.2 Burn math

battery_horizon_hours = usable_kWh / avg_load_kW

diesel_days = (liters * kWh_per_liter * genset_eff) / (daily_gen_kWh)

fuel_cell_days = (H₂_kg * kWh_per_kg) / clinic_air_spine_kWh/day

A.5.3 Tests

- Monthly load-bank for genset; weekly H₂ sensor trip test; IV-curve sampling on PV.

A.5.4 Horizon tile

- SoC_hours, Fuel_days, Inverter_spares, PV_soiling_index.
-

A.6 Waste: MBR cassettes, press cloths, drum yard slots

A.6.1 Floors

- **MBR panels/cassettes: +50% panels** for one cassette.
- **Press cloths:** 2 complete sets (in-use / clean / repair).
- **Drum yard: ≥ 12 months** at median *drums/day* with 20% surge.

A.6.2 Burn math

TMP_slope_trigger → panel_swap_rate

drums/day = (sludge_TSS_kg + filters/solids_kg + ash_kg) / avg_kg_per_drum

yard_horizon_days = (slots_free) / (drums/day)

A.6.3 Horizon tile

- MBR_days, Cloth_sets, Yard_%full, Odor_index.
-

A.7 Food: seed stock, nutrients, fish feed, pantry floors

A.7.1 Floors

- **Seed vault: 3 full crop cycles** for leafy + fruiting + staples; **germ tests** annually.

- **Nutrients (A/B + micros): 90 days** at current m².
- **Fish feed: 60–90 days**; BSF meal buffer ≥ **30 days** of fish ration.
- **Pantry classes:** grains/oils/legumes/sugar/salt each ≥ **90 days**.

A.7.2 Burn math

$\text{seed_horizon_cycles} = (\text{viable_seeds} / \text{seeds_per_m2} / \text{m2_in_cultivation})$

$\text{nutrient_days} = (\text{kg_A} + \text{kg_B}) / (\text{kg_per_day_at_current_EC})$

$\text{fish_feed_days} = \text{kg_feed} / (\text{biomass_kg} * \text{FCR} / \text{days})$

A.7.3 Horizon tile

- Seed_cycles, Nutrient_days, Feed_days, Pantry_days_by_class.

A.8 Clinic: antibiotics, anesthetics, oxygen, disposables

A.8.1 Floors

- **Antibiotics:** Tier A/B ≥ **60–90 days** typical caseload; Tier C sealed with **two-signature**.
- **Anesthetics & circuits:** stock to support **10 general cases + 30 minor**; circuits & filters 1:1 with reprocessing plan.
- **O₂:** ≥ **72 h** autonomy for critical patients (concentrator + cylinders).
- **Dialysis consumables (if active): 30 days** minimum.

A.8.2 Burn math

$\text{abx_days} = \text{defined_daily_DOT} / \text{onhand_DOT}$

$\text{anesthesia_case_days} = (\text{agent_ml_onhand} / \text{ml_per_case_equivalent})$

$\text{O2_hours} = (\text{cylinder_L} + \text{concentrator_output_Lph} * \text{hours}) / \text{patient_Lpm}$

A.8.3 Horizon tile

- ABX_days_A/B/C, Anesthesia_cases, O2_hours_critical, Dialysis_days.

A.9 Tools & Bearings: the hidden governors

A.9.1 Floors

- **Bearings (6xxx/7xxx): 2–3 sets per active pump/UGV.**
- **Seals/O-rings:** kit coverage for **top 50** assemblies; elastomer variety (NBR/EPDM/Viton).
- **Pressure vessels: do not improvise;** spare count noted in §A.4.
- **Fasteners:** A4 stainless **200+** per size (M4–M12).

A.9.2 Burn math

$\text{bearing_days} = \text{sets_onhand} / (\text{mean_time_between_rebuilt} / \text{days})$

$\text{seal_days} = \text{O_ring_kits} / (\text{rebuilt_per_week} * \text{avg_O_rings_per_rebuild})$

A.9.3 Horizon tile

- Bearing_days_top10, Seal_days, Vessel_spare.
-

A.10 Culture: fiction, instruments, paper

A.10.1 Floors

- **Fiction & children's:** ≥ 6 reading hours/person/week for **26 weeks** without repeats (rotation plan).
- **Instruments: 2 strings/woodwinds worth of spares;** pads, reeds, rosin; headset cushions bulk.
- **Paper & ink: 12 months** at current print rate (ledgers + ritual prints).

A.10.2 Burn math

$\text{library_half_life} = (\text{total_titles} * \text{avg_readers_per_title}) / (\text{weekly_reading_sessions})$

$\text{paper_days} = \text{reams_onhand} / (\text{forms_per_day} + \text{culture_prints_per_week}/7)$

A.10.3 Horizon tile

- Reading_weeks, Instrument_spare_index, Paper_days.
-

A.11 Cross-system “Clock Board” (single glance)

- **Air:** HEPA_days | **Water:** Membrane_days | **Power:** SoC_hours | **Waste:** Yard_%full
- **Food:** Seed_cycles | **Clinic:** ABX_days_A/B | **Tools:** Bearing_days_top10 | **Culture:** Reading_weeks

Color rules:

- **Green:** ≥ 90 days (or ≥ 36 h for SoC)
 - **Amber:** 60–89 days (or 24–35 h SoC; yard 70–84%)
 - **Red:** < 60 days (or < 24 h SoC; yard $\geq 85\%$)
-

A.12 Count discipline & testing cadences

- **Cycle counts:** 10% of bins/week $\rightarrow$ 100%/quarter.
 - **Life testing:** pull 1 in 50 items for **bench test** (bearings spin, seals soak, membranes wet-test strip if expiring).
 - **Shelf-life extensions:** only with **documented assay** or function test; move to **Amber** condition.
-

A.13 Example mini-inventory (illustrative snapshot)

Family	Item	Form	On hand	Floor	Burn	Horizon
Air	HEPA H14	m ²	420	360	4.5 m ² /d	93 d
Air	Carbon (clinic)	kg	180	120	1.5 kg/d	120 d
Water	SWRO 8"	elements	36	24	0.15/d	240 d
Water	8" vessels	ea	6	4	0.01/d	600 d
Power	LiFePO ₄	kWh	420	350	—	32 h SoC
Waste	Drum yard	% full	62	<85	+0.6%/wk	38 w
Food	Seed cycles	cycles	3.4	3.0	—	3.4 cyc
Clinic	ABX Tier B	DOT	520	420	6/d	86 d
Tools	6204 bearings	sets	18	12	0.05/d	360 d
Culture	Rag paper	reams	48	26	0.6/d	80 d

A.14 Alarms → Playbooks (bindings)

- **HEPA_days < 60** → *Filter Rationing v1.x* (§15.3).
 - **Membrane_days < 60** → *prep Water Scarcity v2.x* (§15.2).
 - **SoC_hours < 24** → *Silent Mode v2.x* (§15.4).
 - **Yard_%full ≥ 85** → *Yard Drought* (§15.6).
 - **ABX_days_B < 60** → Antibiotic stewardship lock; case review cadence ↑ (§11.3).
 - **Seed_cycles < 3** → double germ tests; tighten crop plan; freeze fruiting expansion (§6).
-

A.15 Storage heuristics (so inventory doesn't rot)

- **Air:** keep carbon sealed, cool, dry; rotate HEPA rows across duty; never “test run” carbon in place.
- **Water:** membranes in original bags, horizontal; avoid UV; track **wet/dry** life separately.

- **Power:** LiFePO_4 at **40–60% SoC**, 2–3%/mo top-up; inverters stored warm/dry.
 - **Clinic:** light-, heat-, moisture-proof; quarantine shelf for anything dubious; stability docs attached.
 - **Seed:** cold, dry, dark; silica packs; annual **germ logs**; refresh via nursery seed grow-outs.
 - **Culture:** paper flat, low-acid; instruments humidity **45–50%**.
-

A.16 People as inventory (skill floors)

- **Minimum certified per system:** Air (3), Water (3), Power (3), Waste (2), Clinic (3), Food (3), Machining (2), Glassing (1), Brewing/Bioprocess (2).
 - Report “**Skill Days**”: $\text{min}(\text{people_certified}) \times \text{days they're available in next 30 d.}$
-

A.17 Rituals of counting (to keep truth sticky)

- **Daily State:** post the eight tiles with horizons.
 - **Weekly Audit:** one owner, one ops, one staff walk the shelves; sign the printout.
 - **Quarterly Blackout Shop:** attempt one critical repair **from banked parts only**; update floors based on what hurt.
-

A.18 Bottom line

The **Clock Inventory** names the few things that, if they end, end everything. Count them as **units of time** (m^2 of filter $\approx$ days of air; membranes $\approx$ days of water; lithium $\approx$ hours of quiet; DOT $\approx$ days of infection control; seeds $\approx$ seasons of food; stories $\approx$ weeks of sanity). Post the horizons where everyone can see them, tie alarms to playbooks, and rebuild the sacrificial stock first after every storm.

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Notes:

- The HEPA H14 and healthcare ventilation references provide the efficiency numbers and pressure-relationship norms that inform our air “floors” and wing controls. [Camfil+1](#)
- WHO GDWQ and RO/MBR literature underpin potable-water targets, pretreatment ladders, and hygiene risk logic. [World Health Organization+2PubMed+2](#)
- Reporting from *The New Yorker*, *WIRED*, *The Guardian*, *Forbes*, and *Business Insider* documents the existence, scale, and features of elite bunkers and compounds (including Hawaii and New Zealand), satisfying the request to include sources on elites’ protected living arrangements. [Business Insider+5The New Yorker+5WIRED+5](#)