

Appendix: representative values, maturity, and evidence

- A1

Design basis and status language

A2

Geometry and pressure segmentation

A3

Selective artificial-gravity calculation

A4

14-sol energy and ingredient origin

MARS

RADIUS

3389.5 KM

MASS

6.42×10^{23}

GRAVITY

3.71 M/S²

A5

Water recovery and passive-power sensitivity

A6

Cleaning and release gates by water class
- A7

Agriculture capacity allocation

A8

Terrace, guild, botanical and fungal functions

A9

Technology maturity and gaps

A10

Failure reserves and restart evidence

PROBUS

9376 KM

ORBITAL

A11

Claim traceability and external source anchors

Appendix values are reference-design inputs, formula outputs, or explicitly labeled sensitivities. They justify concepts already presented; they do not add a second design.

A1. Design basis distinguishes source values from planning assumptions

PARAMETER	WORKING BASIS	STATUS
Crew / mission	15 people; 500-sol commissioned interval inside a five-year settlement horizon	Source value
Mars environment	3.71 m/s ² gravity; 56.5 kPa habitat atmosphere; 18-27°C challenge range	Source value
Concept envelope	500 m square base; 250 m high terraced pyramid	Source geometry; not optimized
Artificial gravity	2 rpm; Mars vertical gravity combines vectorially with centrifugal acceleration	Source method
Food baseline	3,035 kcal / person / sol average; 31.4% modeled Earth-provisioned calorie share	Source value
Crop reference	2,000 m ² plant growth surface: 900 hydroponic; 550 living soil; 300 berry/perennial; 250 aquaponic/wetland	Parametric planning allocation
Water reference	3-5 L/m ² /day crop transpiration; 90-95% recovery sensitivity	Parametric planning assumption
Envelope mass	20-50 kg/m ² panel areal mass, before frame and foundation	Parametric sensitivity only

A2. Pressure segmentation is a mass-and-risk necessity at concept scale

20.83M m³

geometric pyramid volume

353,553 m²

lateral pressure-envelope area

~14,500 t

initial atmosphere mass*

CALCULATION	FORMULA / ASSUMPTION	RESULT
Volume	$V = (1/3)(500\text{ m} \times 500\text{ m})(250\text{ m})$	20,833,333 m ³
Slant height	$s = \text{sqrt}(250^2 + 250^2)$	353.6 m
Lateral area	$A = 4 \times (1/2)(500\text{ m})(353.6\text{ m})$	353,553 m ²
Pressure load	$p = 56.5\text{ kPa}$	56.5 kN outward per m ²
Panel mass sensitivity	$A \times 20\text{-}50\text{ kg/m}^2$	7,100-17,700 t; frame excluded
Atmosphere sensitivity*	$m = pVM/(RT)$; $M=0.030\text{ kg/mol}$, $T=293\text{ K}$	14.5 million kg

**Illustrative ideal-gas mixture. Pressure districts and staged pressurization are therefore core architecture, not presentation detail.*

A5. Water recovery and daylight set the operating burden

Reference crop-water circulation = 8 m³/sol midpoint. Lighting envelope begins with the existing 0.31–0.56 MW all-electric planning range; passive/daylight cases are sensitivities to validate by site and season.

NET CROP-WATER MAKEUP AT 8 M³/SOL GROSS STREAM	GROSS FLOW	AVERAGE FOOD-SYSTEM POWER SENSITIVITY RECOVERY / NET EFFECT
Crew consumption, food prep, hygiene	~57 L/sol for 15 crew	At 90% recovery: ~6 L/sol net make-up before other losses
Crop transpiration	2,000 m² x 3-5 L/m²/sol = 6-10 m³/sol	At 90-95% condensate recovery: 0.3-1.0 m³/sol net loop loss
Cleaning, processing, animal, research	Not closed	Must be added by module and use class

LOAD	LOW	HIGH	BASIS
Crop lighting	5.0 MWh/sol	9.0 MWh/sol	2,000 m² x 180-250 W/m² x 14-18 h
Climate, pumps, water treatment	+35%	+35%	Planning factor applied to lighting
Kitchen, cold storage, controls	0.7 MWh/sol	1.4 MWh/sol	30-60 kW average

Design consequence: water must close above 95%, while photon capture, spectral control and thermal rejection deserve the earliest full-scale site tests because lighting and heat—not nutrient pumping—dominate power.

NASA ECLSS demonstrated 98% water recovery; values shown apply that benchmark as a food-system design target, not as a claim of integrated RAMS performance.

A6. Cleaning and release gates are specific to water class

RAMS closes water without pretending all water is interchangeable. Every loop has a defined treatment train, release measurement and allowable destination; cross-class transfer requires the stricter receiving gate.

WATER CLASS	ORIGIN	CLEANING / PURIFICATION TRAIN	RELEASE MEASUREMENTS	NORMAL DESTINATION
Potable + condensate	Apex condenser; crew latent; detoxified ice water	Particulate filter → adsorption / ion exchange → catalytic oxidation → UV + controlled residual disinfection / mineral balance	TOC, conductivity, microbial, target ions, perchlorate guard	Potable tank; kitchen; clean makeup header
Hydroponic nutrient	Root cassettes and local sumps	Screen / disc filter → ultrafiltration → UV-C or ozone sidestream → activated carbon as needed → re-dose ions	pH, EC, DO, temperature, turbidity, ion profile, pathogen screen	Same crop-zone reservoir; clean makeup only
Soil + wetland	Grove drainage, beds and constructed wetland	Sediment trap → mineral-media filter → biofilter / wetland → ultrafiltration; periodic salt bleed	Turbidity, EC, N/P/K balance, indicator microbes, target contaminants	Irrigation header; never direct potable return
Grey / food-process	Handwash, kitchen and food-processing water	Equalization → membrane bioreactor → adsorption / ion exchange → catalytic or UV oxidation → final membrane polish	TOC, ammonia, conductivity, microbial and process-specific residues	Non-potable clean tank; potable only after full potable gate
Blackwater + nutrients	Urine, fecal solids and high-strength organics	Water recovery / distillation; solids digestion + thermal sanitation; nitrification; phosphate / mineral recovery	Pathogens, pharmaceuticals, metals, salinity, nutrient composition	Source-coded fertilizer stock after release; residues to secure processing
Industrial brine	Regolith wash and ion-exchange regenerant	H ₂ -fed anoxic membrane-biofilm reactor → gas/liquid separation → electrodialysis / crystallization → water polish	Perchlorate, chlorate, chloride, pH, salinity and reactor activity	Industrial wash-water recycle; chloride product tank
Clean-in-place rinse	Isolated pipe, tank, fermenter and root-loop sanitation	Drain → hot-water / steam or compatible oxidant cycle → neutralize → validated final rinse → recover	ATP/bioburden proxy, TOC, conductivity and sanitizer residual	Greywater train; equipment released back to its original class

A7. The agriculture split is a testable capacity allocation

PRODUCTION METHOD	SURFACE	SHARE	PRIMARY ROLE	ACCEPTANCE EVIDENCE
Recirculating hydroponic / soilless	900 m²	45%	Fast-cycle fresh crops, berries, vines and propagation	Stable yield; water and nutrient recovery; automated pollination and harvest staging
Living-soil terraces	550 m²	27.5%	Staples, roots, pulses, oilseeds, fodder and soil succession	Rotation performance; nitrogen and carbon balance; no salt or toxicant accumulation
Berry / perennial cartridges	300 m²	15%	Fruit, shrubs, flavor, wellness, woody biomass and habitat	Full cartridge cycle; pest recovery; pruning cascade; preserved surplus
Aquaponic / wetland beds	250 m²	12.5%	Aquatic plants, optional protein, nutrient capture and water polishing	Feed and nutrient balance; solids recovery; water-quality improvement without loop contamination
TOTAL PLANT GROWTH SURFACE	2,000 m²	100%	Parametric trade-study basis	14-sol autonomous run with branch bypass and complete mass-flow accounting

900 + 550 + 300 + 250 = 2,000 m². Fungi, fermentation and animals are capacity-based modules and are excluded from this surface total.

A8. Every botanical earns its place several times

The living chemical bank is distributed through the food ecology. Selection combines crew-use chemistry, food form, succession role, nutrient/water work, biomass destination, and the value of retained data.

ZONE / GUILD	REPRESENTATIVE SYSTEMS	CREW USE + PRIORITY CHEMISTRY	ECOLOGICAL WORK	CO-PRODUCT / NEXT USE
Apex / cool-dry edge	Wira-wira; jimbu; timur; Rhodiola; nettle; flax	Respiratory/digestive foods; terpenes, sanshool, salidroside/rosavins	Low canopy; pollinator and aromatic edge; cool dry seed zone	Seasoning; seed; fiber; cleared litter to compost
Upper dry shrub	Sea buckthorn; goji; muña; huacatay	Tart fruit and teas; carotenoids, flavonols, polysaccharides, volatile oils	Root binding; shrub structure; pest-management and browse diversity	Berry pomace to ferment/feed; prunings to fiber/biochar
Warm inner understory	Ginger; turmeric; pippali; amla juveniles	Nausea/inflammatory food modules; gingerols, shogaols, curcuminoids, turmerones, piperine	High-value shade crops; aromatic pressure; rapid harvest cycles	Rhizome marc to fungal substrate; sauces, ferments and extracts
Humid perennial root	Mai Men Dong; Tian Men Dong; edible lily; Polygonatum	Steamed foods, soup and decoction; saponins, mucilage and polysaccharides	Living mulch; deep root volume; seasonal nutrient storage; moist-bed stability	Root fiber to fungi/compost; flowers and edible starch
Central grove	Mulberry; loquat; amla; willow; medicinal shrubs	Fruit, leaf and bark programs; anthocyanins, triterpenes, emblicanins, salicylates	Canopy; shade; litter; woody carbon; habitat and browse structure	Fruit/pomace; fodder where released; wood, fiber, biochar
Wetland / aquatic	Centella; Plantago; Coix; Alisma; duckweed	Fresh greens, grains and fluid/urinary research; triterpenes, mucilage, sterols	Nutrient capture; root polishing; evaporation surface; aquatic feed	Protein feed; mulch; treatment biomass only after contaminant release
Fungal shade / vessels	Tremella; Poria; oyster/shiitake; koji/tempeh cultures	Soup, protein and ferments; beta-glucans, ergothioneine, triterpenes and enzymes	Primary decomposition; lignocellulose conversion; soil aggregation and symbiosis	Mycoprotein; enzymes; chitosan films; spent substrate to soil/feed after assay

Priority molecules are research and manufacturing targets linked to accession, chemotype, growth regime, preparation, response and residue route in the RAMS meal-plan workbook.

A9. Frontier integration built from legible unit operations

RAMS does not require every subsystem to mature at once. Proven equipment carries early food production while lower-maturity modules earn authority through isolated pilots, measured product release and explicit five-year gates.

MATURITY BAND	SYSTEMS USED	MISSION ROLE	GAP TO CLOSE
Operational / high maturity	Pumps, valved pipe, tanks, heat exchangers, condensers, HEPA filtration, UV, adsorption / ion exchange, food fermentation, controlled-environment hydroponics	Carries startup water, air, sanitation and dependable crop production	Mars-rated maintenance, dust exclusion, spares strategy, low-g hydraulics and long-duration material compatibility
Demonstrated subsystem / adaptation required	Passive porous-tube irrigation, membrane bioreactors, nutrient recovery, automated crop imaging, robotic handling, sealed thermal ice extraction	Reduces power and labor; recovers water and minerals; supplies site water	Integrated Mars-pressure/temperature tests, salt tolerance, fouling control, autonomous recovery and validated mass balance
Frontier pilot	Martian perchlorate concentration + biological destruction, chloride recovery, large mixed-guild ecology, medicinal chemotype production	Converts local hazard into reusable water/mineral streams and a functional chemical bank	Mixed-salt kinetics, reactor oxygen balance, genetic/enzymatic stability, contaminant fate, preparation standards and release analytics
Later industrial / settlement expansion	Molten-regolith electrolysis, structural glass/ceramics, rotating gravity annulus, ruminant breeding and dairy	Turns Martian minerals and ecological surplus into construction, Earth-gravity access and steppe-type trophic capacity	Power and heat rejection, electrode life, gas/metal separation, structural integration, animal gravity/reproduction evidence and welfare operations

Deployment rule: a frontier module may process material from day one, but its output only enters a human, crop or animal loop after the relevant chemical, microbial and mass-balance gate has been demonstrated repeatedly.

APPENDIX

A10. Selective containment preserves healthy exchanges

FAILURE	REDUNDANCY / RESERVE	FAILSAFE	RESTART EVIDENCE
Panel crack	Adjacent pressure districts; repair stock	Automatic isolation; shutters; local evacuation	Leak and proof-pressure test
Power loss	Primary + battery / thermal stores; cold stores	Biological load shed order; manual controls	Stable atmosphere, water, temperature
Air-quality upset	Shared inventory; local conditioning; O2 / CO2 stores	Close only the affected branch; maintain crop-human gas exchange elsewhere	Stable gases, humidity, particulates and branch pressure
Water contamination	Clean-water header; branch storage; polishing bypass	Close suspect branch; keep unaffected crop and habitat circulation online	Chemistry, microbial and nutrient release
Crop / pollinator failure	Alternate methods; seed / pollen / frozen food	Bypass affected cartridge; menu rebalanced	Clean replant, reconnection and yield trend
Microbial imbalance	Reference cultures; physicochemical backup	Reactor isolated; food/feed use suspended	Identity, metabolite and nutrient tests
Animal disease	Genetic reserve; feed trace; separate enclosure	Veterinary quarantine; milk and waste separation	Diagnostics, welfare and manure sanitation

Reliability = low-consequence failure domains + reserves + practiced recovery - not the absence of biological variability.

A11. Every claim has an evidence anchor and validation test

DECK CLAIM	PRIMARY ANCHOR	RAMS VALIDATION / EVIDENCE
Integrated food system spans production through waste	Mars to Table Challenge deliverables and $\leq 50\%$ Earth-food constraint	14-sol meal-plan mass/origin audit + end-to-end batch trace
Water moves through class-specific pipes, tanks and treatment trains	NASA ISS water-management and WPA filtration / ion exchange / catalytic-oxidation practice	Full hydraulic model; tracer test; leak isolation; cross-class release-gate challenge
Ice water is captured from a sealed heated process	NASA Mars soil-water extraction and capture studies	Dust-tight retort mass/energy balance; condenser yield; raw-water contaminant characterization
Perchlorate is concentrated, destroyed and converted to chloride	NASA NIAC perchlorate biocatalysis + ion-exchange/biological brine research	Regolith wash balance; ClO_4^- destruction kinetics; chloride and oxygen fate; water recycle
Air and humidity remain closed while heat is rejected	NASA CELSS humidity recovery and spacecraft air-filtration functions	Zone airflow CFD/mockup; condensate recovery; filter loading; damper isolation and thermal rejection
Passive nutrient delivery can remove pumps from some root zones	NASA PONDS / passive porous-tube nutrient delivery	Multi-crop Mars-g analog with clogging, salinity and dry-out fault tests
Lighting and climate dominate crop-system power	NASA bioregenerative life-support and vertical-farming literature	Full-section photon/heat model + seasonal site test + load-shed crop priorities
Waste can be converted by compartmented microbial and plant processes	ESA MELiSSA compartments: liquefaction, carbon removal, nitrification, photosynthesis	Source-coded residue $\rightarrow$ mineral nutrient $\rightarrow$ crop/fungal biomass balance
Food must support physiology, morale and variable needs	NASA human-system integration/nutrition sources + Challenge requirements	Individual plate engine, acceptability logs, condition modules and nutrition verification
RAMS-specific geometry, guilds, menu and materials loops	RAMS Integrated System Definition + RAMS 14-Sol Meal Plan	Pressure-district mockup, 14-sol autonomous operation, failure recovery and five-year gates

BERRY SORBET

BATCH NO.
0702

180 GRAMS / CREW SERVING

BATCH YIELD
15 SERVINGS

235KCAL PER SERVING	MACROS / G P 9 • C 34 • F 7 FIBER 6 G	SUPPLEMENT FROZEN
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INGREDIENTS / SOURCE

STRAWBERRIES 100 G [MP] • CULTURED SOY 55 G [MF/MA]
BERRY SYRUP 20 G [MP] • WATER 5 G [RM]

PREP + HOLD FREEZE-CHURN + PORTION MAINTAIN FROZEN STORAGE	NEXT USE / CLOSED LOOP SOFTENING SURPLUS BECOMES SOL 08 SHAKE BASE
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SOURCE KEY

MA MARS ANNUAL CROP • MP MARS PERENNIAL • MF MARS FUNGUS / FERMENT • RM RECOVERED MINERAL

0.38G PYRAMID FOOD SYSTEM / SOL 07 / SUPPLEMENT 02

SEED BRITTLE

BATCH NO.
0701

55 GRAMS / CREW SERVING

BATCH YIELD
15 SERVINGS

235KCAL PER SERVING	MACROS / G P 10 • C 26 • F 11 FIBER 5 G	SUPPLEMENT AMBIENT
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INGREDIENTS / SOURCE

SUNFLOWER SEED 25 G [MA] • SESAME 15 G [MA]
BERRY SYRUP 12 G [MP] • SALT 1 G [RM]
SPICE 2 G [EP]

PREP + HOLD COOK SYRUP, PRESS THIN + COOL DRY STORE AIRTIGHT FOR 4 SOLS	NEXT USE / CLOSED LOOP FRAGMENTS TOP PORRIDGE SCORCHED BATCHES → NON-FOOD WASTE
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SOURCE KEY

EP EARTH-PROVISIONED • MA MARS ANNUAL CROP • MP MARS PERENNIAL • RM RECOVERED MINERAL

0.38G PYRAMID FOOD SYSTEM / SOL 07 / SUPPLEMENT 01

BERRY OAT BAR

BATCH NO.
1101

80 GRAMS / CREW SERVING

BATCH YIELD
15 SERVINGS

235KCAL PER SERVING	MACROS / G P 10 • C 31 • F 9 FIBER 6 G	SUPPLEMENT AMBIENT
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INGREDIENTS / SOURCE

OATS 32 G [EP] • BERRY PASTE 25 G [MP]
SUNFLOWER BUTTER 15 G [MA] • FLAX 8 G [MA]

PREP + HOLD BAKE, COOL + SEAL AMBIENT HOLD FOR 3 SOLS	NEXT USE / CLOSED LOOP CRUMBS TOP CULTURED SOY
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SOURCE KEY

EP EARTH-PROVISIONED • MA MARS ANNUAL CROP • MP MARS PERENNIAL

0.38G PYRAMID FOOD SYSTEM / SOL 11 / SUPPLEMENT 01

CACAO-SESAME TRUFFLE

BATCH NO.
1402

60 GRAMS / CREW SERVING

BATCH YIELD
15 SERVINGS

235KCAL PER SERVING	MACROS / G P 11 • C 25 • F 11 FIBER 5 G	SUPPLEMENT CHILLED
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INGREDIENTS / SOURCE

SESAME 22 G [MA] • SUNFLOWER BUTTER 18 G [MA]
CACAO 8 G [EP] • BERRY PASTE 8 G [MP]
PEA PROTEIN 4 G [MA]

PREP + HOLD MIX, PORTION + CHILL HOLD ≤ 4°C FOR 3 SOLS	NEXT USE / CLOSED LOOP CRUMBS ENRICH THE NEXT PORRIDGE PACKAGING IS RECYCLED
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SOURCE KEY

EP EARTH-PROVISIONED • MA MARS ANNUAL CROP • MP MARS PERENNIAL

0.38G PYRAMID FOOD SYSTEM / SOL 14 / SUPPLEMENT 02