OSY-E PROPELLANT PRODUCTION, STORAGE, AND REFUELING ARCHITECTURE

Revision: Rev 1
Status: Integrated Baseline (Single Document)
Date: 2025-12-12
Owner: OSY-E Engineering

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Authoring Context: Consolidated from the full design evolution captured in the referenced chat session.

REVISION HISTORY

- Rev 1 - Initial full baseline (this copy includes formatting corrections: removed non-ASCII artifacts; corrected section numbering).
- Incorporates: RAFTI vs heavy transfer conclusions; fuel wheel storage-only decision; service-bay fueling via Fueling Nodes; spine face zoning; steam/SOEC/buffers; NH3 and CH4 synthesis; SMR scale-up; tug-controlled proximity ops.

1. PURPOSE

Define the end-to-end OSY-E architecture for producing propellants from onboard water, storing and conditioning them, and delivering them safely to visiting spacecraft for refueling.

This document is the authoritative single-source baseline for the OSY-E propellant production, storage, and refueling system.

- Water transport from habitat wheel storage to fuel production
- High-temperature steam generation (approximately 750 C) feeding SOEC electrolysis banks
- Hydrogen and oxygen buffering, conditioning, compression, and optional liquefaction
- Optional synthesis conversion paths: ammonia (NH_3) and methane (CH_4)
- Bulk propellant storage and conditioning using a rotating fuel wheel (tank farm)
- Stationary distribution to non-rotating service bays via modular Fueling Nodes
- Growth path from early operations (1-2 vehicles at a time) to mature cadence (4-5 heavy refuels per day)
- Power and thermal scaling: initial electric heating, later thermal-first SMR modules (4 pods) with intermediate heat transfer loops
- Safety zoning, venting strategy, isolation philosophy, and operational doctrine

2. SYSTEM CONTEXT AND DRIVERS

- Water storage is located on the habitat wheel.
- Fuel production and the fuel tank farm are located near the far end of the service bay region, opposite the habitat wheel.
- Spine length is approximately 1 km between habitat wheel and fuel production zone, with 20 service bays at 100 m junction spacing.
- OSY-E will be in GEO and will serve as a refueling, construction, repair, and logistics hub.
- Early traffic likely supports 1-2 refueling operations at a time.
- Mature traffic may reach 4-5 heavy refuels per day over 15-20 years.
- OSY-E retains 100 percent control of close-in docking and positioning.
- Visiting vehicles enter an OSY handoff box, transition to passive mode, and are handled by OSY Class A tugs into service bays.

3. TOP-LEVEL DECISIONS (BASELINE)

The following decisions define the baseline architecture and constrain downstream subsystem designs.

- Decision A: RAFTI is used for small satellite and small tug refueling only.
- Decision B: Heavy vehicle refueling occurs in non-rotating service bays. Visiting vehicles do not dock to rotating structures (fuel wheel or habitat wheel).

- Decision C: The fuel wheel is a tank farm for storage and conditioning only. It is not a customer docking interface.
- Decision D: Fuel delivery uses stationary day tanks and pump skids (Fueling Nodes). Rotary joints and wheel transfer operate at steady replenishment rates, not peak fueling rates.
- Decision E: Fuel production is modular and scalable from electric heating to 4 SMR pods (thermal-first), using an intermediate thermal transfer loop feeding modular steam generator skids.

4. OSY-E GEOMETRY AND SPINE FACE ZONING

- Define four spine faces: North (water transport trunk, conditioned volume), South (propellant distribution trunks and fueling hardware, hazard/industrial routing), East/West (corridors, bay access, logistics, maintenance).
- 20 service bays spaced every 100 m along the spine by East/West cross corridors.
- Bays 19-20 are closest to the fuel production and tank farm end; bays 1-2 are closest to the habitat wheel.
- Early fueling operations prioritize bays 19-20 for clearance and maneuvering.
- First Fueling Node serves bays 17-20, enabling flexibility without rebuilding plumbing.

5. WATER TRANSPORT ARCHITECTURE (HABITAT -> PRODUCTION)

- Bulk water stored on the habitat wheel for life support, shielding, and industrial feedstock.
- Water exported via a rotary interface at the habitat wheel hub into the stationary spine trunk.
- Water trunk runs along the North face inside a conditioned corridor to prevent freezing.
- Insulation, heat trace, and optional recirculation maintain an above-freezing margin.
- Sectional isolation valves at bay junction intervals (100 m nodes).
- Leak detection, pressure monitoring, and flow monitoring distributed along the trunk.
- Design supports repairability and isolation without shutting down the entire water supply.

6. FUEL PRODUCTION PLANT ARCHITECTURE (PRODUCTION ZONE)

Fuel production occupies the terminal segment of OSY-E beyond bays 19-20, subdivided into the following zones:

- P1: Steam generation + SOEC banks (industrial hot zone)
- P2: Gas buffering + conditioning + compression + drying
- P3: Synthesis skids (NH_3 and CH_4), modular and optional by phase

- P4: SMR reactor pod mounts + radiator fields (furthest from bays and habitat)
- End-to-end process flow: water -> preheat -> 750 C steam -> SOEC -> H2 + O2 -> buffers -> conditioning -> storage (fuel wheel) -> day tanks (Fueling Nodes) -> service bays -> customer vehicles.

7. HIGH-TEMPERATURE STEAM GENERATION (APPROXIMATELY 750 C)

- Phase 0-1: Electric steam generation (initial). Water is routed through modular steam generator skids producing steam at approximately 750 C.
- Induction coils heat a metallic susceptor/heat exchanger (not direct water heating).
- Each SOEC bank is fed by a dedicated steam generator skid co-located in Zone P1.
- Electric power supplied initially by solar and batteries.
- Phase 2+: SMR-driven thermal steam generation (scale). Pebble Bed SMR pods provide thermal energy to the steam generator skids.
- No direct reactor-to-water coupling.
- Thermal architecture: primary loop (reactor), intermediate thermal transfer loop (isolated, controlled), secondary steam generator loop (water to steam).
- Modular steam skids remain the scaling unit to match SOEC bank growth.

8. SOEC ELECTROLYSIS BANKS

- Each SOEC bank module includes: 750 C steam inlet manifold; SOEC stack array; hydrogen product manifold; oxygen product manifold; condensate recovery and water recycle; thermal insulation and controlled warmup/cooldown procedures.
- Scaling: start with 1 bank in Phase 0; add identical banks as power and water throughput increases.
- Banks connect to common steam and product headers while retaining independent steam skid feeding.

9. H2 AND O2 BUFFERS AND CONDITIONING

- Phase 0 buffering: H2 buffered as high-pressure gas (GH2) with drying/purification; O2 buffered as high-pressure gas (GO2) with drying/purification.
- Conditioning includes compression, drying, filtration, and purity monitoring.
- Cooling and liquefaction are introduced when justified by economics and throughput.
- Hydrogen storage form is intentionally phase-dependent: GH2 early; LH2 optional later.
- Storage choice does not alter service-bay delivery architecture.
- Conditioned products transfer into the fuel wheel tank farm for long-term storage and thermal conditioning.

10. OPTIONAL DOWNSTREAM SYNTHESIS MODULES

- Ammonia (NH_3) synthesis module: inputs H_2 and N_2; modular Haber-Bosch skid; output NH_3 condensed and stored in tank farm; N_2 sourcing is a Phase 0 TBD (shipped initially if needed).
- Methane (CH_4) synthesis module: inputs H_2 and CO_2; modular Sabatier skid; outputs CH_4 + water; water recycled to the inlet manifold; CH_4 conditioned and liquefied to LCH_4 for tank farm storage; CO_2 sourcing is a Phase 0 TBD (shipped initially if needed).

11. FUEL WHEEL (TANK FARM) ARCHITECTURE

- Role: bulk storage and conditioning of LOX, LCH_4, NH_3, and optional LH_2. Provides thermal stability and improved liquid acquisition at outlets. Not used as a customer docking interface.
- Slow rotation provides low-g liquid positioning inside tanks.
- Internal baffles and redistribution pumps manage tank balance and outlet stability.
- Fuel wheel balance is an internal station function, decoupled from customer docking events.
- Fuel wheel transfers product to stationary systems through rotary interfaces.
- Rotary interfaces are sized for steady replenishment, not peak customer fueling.

12. PROPELLANT DISTRIBUTION TRUNKS (SOUTH FACE)

- South-face trunk headers (stationary): LOX trunk; fuel trunk (CH_4 and/or NH_3, optional LH_2); purge gas trunk (GN_2 and/or He); vent/relief header routed to a dedicated vent mast at the depot end.
- Trunks are sized for mature-state multi-node demand.
- Rotary interfaces are designed for continuous baseline replenishment.
- Peak fueling flow to customers is provided by stationary pumps and day tanks.

13. FUELING NODES (PUMPS + DAY TANKS) AND BAY SERVICING

- Fueling Node definition: a centralized, stationary fueling plant module that services four adjacent service bays via a selectable manifold.
- Node A (initial deployment) serves bays 17, 18, 19, 20. Bays 19-20 are prioritized for early fueling operations due to clearance and maneuverability.
- Node components: LOX day tanks; fuel day tanks (CH_4/NH_3, optional LH_2); rigid cryogenic day tanks equipped with PMDs (no bladder expulsion for cryogens); pump skid with N+1 redundancy; selectable valve manifold; double block and bleed per bay branch; check valves/backflow protection; purge and chilldown capability; instrumentation; ESD integration.

- Operations: early phases run one high-flow fueling operation per node at a time. Other bays may stage, purge, leak-check, and chilldown prep while one bay fuels.
- Expansion: add additional Fueling Nodes upstream as demand grows (example Node B for bays 13-16). Nodes attach to standardized branch points on the trunk system.

14. SERVICE BAY FUELING KIT (CUSTOMER INTERFACE)

- Each fueling-capable bay includes: umbilical deployment mechanism; LOX fill line; fuel fill line; purge gas line; chilldown capability; emergency disconnect; independent bay-side isolation valves and sensors; structural clamp points for vehicle restraint during fueling.
- Vehicles refuel in non-rotating service bays under OSY tug control and bay restraint systems.

15. PROXIMITY OPS AND DOCKING DOCTRINE (OSY CONTROLLED)

- Visiting vehicles fly to an OSY-defined handoff box and transition to passive mode.
- OSY Class A tugs take full control for close-in translation and attitude positioning.
- Tugs guide the vehicle into the designated bay.
- Vehicle is secured using bay restraint hardware before umbilicals connect.
- This doctrine eliminates reliance on visiting vehicle autonomy near station structure.

16. THERMAL MANAGEMENT AND HEAT REJECTION

- Thermal loops (segregated): reactor primary loop (closed, isolated); intermediate thermal transfer loop; steam generator loop (water to steam); SOEC thermal management loop; liquefaction/conditioning cooling loops; synthesis skid thermal control loops.
- Dedicated radiator fields near the production zone and reactor pods.
- Radiator placement avoids plume impingement, line-of-sight exposure to sensitive areas, and interference with docking corridors and solar disk operations.

17. SMR PEBBLE BED REACTOR PODS (4 BOLT-ON MODULES)

- Four bolt-on SMR pods with standardized electrical and thermal interfaces.
- Shadow-shielded orientation away from habitat wheel and crew corridors.
- Thermal-first assets; electrical generation is secondary and routed to station power buses as available.

- Reactor pods are located beyond the production zone at the extreme end of OSY-E, outside service bay traffic lanes and away from habitat line-of-sight.
- Scale-up: Pod 1 provides baseline thermal support for sustained steam generation and initial production scaling. Pods 2-4 provide stepwise throughput increases enabling multi-node fueling cadence and synthesis module activation.

18. SAFETY, HAZARD ZONING, AND VENTING

- Zoning: North face conditioned utility zone (water); South face propellant hazard/industrial zone; production zone high-temperature and reactive-gas industrial zone; reactor zone radiation-controlled industrial zone.
- Isolation philosophy: trunk isolation segments at bay nodes; node isolation from trunks; bay isolation with double block and bleed plus purge; station-level ESD integrated with local skid control.
- Dedicated vent mast near depot end for oxygen vent, hydrogen vent, purge exhaust, and emergency relief.
- Vent routing avoids plume impingement on structure, solar disk, comms arrays, and active bays.

19. PHASED BUILDOUT

- Phase 0: water trunk operational; electric steam generator skids and 1 SOEC bank operational; GH2/GO2 buffers and basic conditioning; fuel wheel tank farm operational; Fueling Node A operational for bays 17-20 (focus bays 19-20); single high-flow refuel at a time.
- Phase 1: additional SOEC banks and buffer expansion; conditioning and compression expansion; synthesis module interfaces prepared (optional activation).
- Phase 2: SMR Pod 1 integrated via intermediate thermal transfer loop; expanded steam generation and SOEC throughput.
- Phase 3: Pods 2-4 added; multiple SOEC banks; NH3 and CH4 synthesis skids active as required; additional Fueling Nodes installed upstream for parallel ops; mature cadence supports 4-5 heavy refuels/day through scheduling and modular expansion.

20. OPEN ITEMS (TBD FOR REV 2 WORK PACKAGES)

- Define initial propellant set for early operations (LOX/CH4 baseline assumed; NH3 and LH2 optional by phase).
- Define target per-bay fueling flow rates (drives pump sizing and line diameters).
- Define rotary interface requirements (water export and fuel wheel export), including seal approach and redundancy.
- Define N2 sourcing strategy for NH3 (initial shipment vs later generation).
- Define CO2 sourcing strategy for CH4 (initial shipment vs later capture/import).

- Define purity specifications for rocket-grade LOX and fuel products and required conditioning steps.
- Define detailed vent mast geometry and plume analysis constraints relative to station geometry.
- Define detailed safety PLC boundaries and ESD logic architecture.

21. DECISION STATEMENT

- Water is transported from habitat storage along the North face in conditioned routing to prevent freezing.
- Fuel production is performed at the depot end using modular 750 C steam generation feeding SOEC banks.
- Hydrogen and oxygen are buffered and conditioned, then routed into tank farm storage on the rotating fuel wheel.
- Optional synthesis converts a portion of hydrogen into ammonia and methane using modular skids.
- The fuel wheel is storage and conditioning only and is not used as a customer docking interface.
- Propellants are distributed along the South face in a hazard-zoned trunk system to modular Fueling Nodes.
- Fueling Nodes (starting at bays 17-20) provide stationary high-flow fueling to non-rotating service bays.
- OSY Class A tugs control all close-in docking and bay parking operations.
- Thermal and production scaling is achieved via four bolt-on Pebble Bed SMR pods feeding steam generation through an intermediate thermal transfer loop.
- This baseline is designed to scale linearly from early operations to mature cadence without redesigning the backbone.

END OF DOCUMENT