LUNET

Lunar Utility Node & Exchange Terminal

A standardized infrastructure for lunar mobility,
ISRU integration, and propellant production

Aegis Station Infrastructure
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1. Overview

The Lunar Utility Node & Exchange Terminal (LUNET) is a standardized network of surface and orbital utility nodes designed to support routine, repeatable lunar transportation and operations. LUNET enables refueling, recharging, diagnostics, and logistics coordination for lunar surface and cislunar vehicles.

Rather than treating lunar mobility as a sequence of bespoke missions, LUNET establishes persistent infrastructure. It allows vehicles to carry only the propellant required for the next leg, enabling low-delta-v hops between nodes and supporting sustained operational cadence.

System Characteristics

- Distributed surface and orbital utility nodes
- Refueling, recharging, diagnostics, and logistics exchange
- Designed for integration with lunar and orbital ISRU pipelines
- Independent of any single vehicle or station architecture
- Scalable from initial pathfinder nodes to full network coverage

Strategic Role

By decoupling vehicles from mission-complete propellant loads and enabling staged exchange across persistent nodes, LUNET transforms lunar ISRU from demonstration into daily operations that can be planned, relied upon, and scaled.

2. ISRU-Aligned Operations

LUNET is designed around a water-buffered ISRU architecture. Water absorbs uncertainty and provides long-duration buffering, oxygen naturally lends itself to inventory, and hydrogen is treated as a short-dwell, near-use commodity rather than a bulk storage product.

This approach reduces power burden, tank mass, and system brittleness while improving operational resilience and scalability.

Water as the Network Commodity

A central architectural decision in LUNET is that water—not liquid hydrogen—is the commodity that moves through the network. Each node receives water deliveries and performs electrolysis and liquefaction locally. This converts a network-scale cryogenic logistics problem into a contained, node-local equipment problem.

Water is the ideal transport commodity for lunar infrastructure. It is indefinitely stable with no boil-off, requires no cryogenic insulation or vacuum-jacketed transfer lines, can be handled with standard elastomeric seals and simple disconnectable fittings, stored in rigid tanks or flexible bladder tanks, serves as radiation shielding while in storage, and presents no explosion hazard. A water leak is a maintenance issue, not a safety emergency.

3. Hydrogen Infrastructure Philosophy

Liquid hydrogen (LH_2) presents unique infrastructure challenges at every stage: storage, transfer, and consumption. LUNET's architecture is designed around these constraints rather than attempting to overcome them through brute-force engineering.

Why Hydrogen Is Short-Dwell

The short-dwell principle is driven not only by boil-off losses but by the cumulative degradation of transfer infrastructure itself. LH_2 transfer lines degrade through several mechanisms:

- **Thermal cycling fatigue.** Every fill/drain cycle takes hardware from ambient to 20 K and back. Bellows, flex joints, and bayonet connections accumulate fatigue damage. Vacuum-jacketed lines with bellows are typically rated for hundreds to low thousands of thermal cycles.
- **Hydrogen embrittlement.** Even well-chosen austenitic stainless steels can develop micro-cracking over long service lives, particularly at welds and heat-affected zones. This is slow, progressive, and essentially irreversible.
- **Vacuum jacket degradation.** Multilayer insulation performance degrades if the vacuum annulus is compromised. Getter materials saturate over time. Once boil-off rates climb, the entire line section typically needs replacement.
- **Seal wear.** PTFE cold-flows under sustained compression. Indium gaskets are single-use by design. Spring-energized seals lose preload over many thermal cycles.

On the lunar surface, replacing LH_2 transfer lines is a major operation requiring warming, purging, joint breaking, seal replacement, leak checking, vacuum jacket re-evacuation, and re-cooling—a multi-day procedure even on Earth with trained crews and full infrastructure support.

Produce Near, Consume Fast

LUNET's architecture minimizes LH_2 exposure by producing hydrogen as close to the point of use as possible. Each node electrolyzes water and produces LH_2 locally, with a short cryogenic path from electrolyzer to liquefier to fill coupling—typically a few meters of plumbing. This plumbing still degrades, but it is local, short, and a node-level maintenance problem rather than a network-wide infrastructure vulnerability.

This “produce near, consume fast” approach is a fundamental differentiator from depot-centric architectures that assume bulk LH_2 movement across the lunar surface.

Cryogenic Seal Consumables

Every disconnectable LH_2 interface at a LUNET node requires consumable seals. Materials that function at 20 K include PTFE and PCTFE fluoropolymers, indium crush gaskets, spring-energized seals with PTFE jackets and Inconel springs, and austenitic stainless steel or copper C-ring seals. All of these have finite service lives. Seal kits are a standard logistics line item at every LUNET node, and fill coupling interfaces should be designed for minimum disconnect cycles.

4. Node-Level Electrolysis and Power

Electrolysis at Node Scale

PEM (proton exchange membrane) electrolyzers are inherently modular, commercially available from single-kilowatt to megawatt scale with identical core stack architecture. A LUNET node filling a rover with a few hundred kilograms of propellant between hops requires electrolyzer capacity on the order of a few kilowatts to approximately 20 kW, well within demonstrated hardware scale.

Solid oxide electrolysis (SOEC) offers higher efficiency at high operating temperatures. On the lunar surface, co-location with thermal management systems allows waste heat to improve SOEC efficiency rather than being purely a liability.

Liquefaction Energy Requirements

The theoretical minimum energy to liquefy hydrogen from room temperature is approximately 3.9 kWh/kg. Real-world small-scale liquefiers require 25–40 kWh/kg. Lunar conditions—radiative heat rejection to deep space and access to passively cold thermal mass—provide an estimated 20–30% improvement, yielding a working range of 18–30 kWh/kg for a node-scale lunar liquefier. Electrolysis adds approximately 50–55 kWh per kg of H_2 including system inefficiencies.

Power Sizing Reference

The following table shows total node power requirements for the hydrogen production chain (electrolysis plus liquefaction) at different operational cadences, assuming a reference fill of 100 kg LH_2 per vehicle:

Fill Interval	Electrolysis	Liquefaction	Total Power
14 days (1 per lunar day)	~16 kW	~7 kW	~23 kW

3 days	~75 kW	~35 kW	~110 kW
Daily fills	~230 kW	~104 kW	~334 kW

Solar Array Sizing

Lunar solar arrays deliver approximately 200–250 W/m^2 at mid-latitude sites with average sun angles (accounting for panel efficiency, packing factor, and dust degradation). At polar sites with near-horizontal illumination, effective irradiance drops to approximately 80–120 W/m^2, though tower-mounted arrays can improve this.

Fill Interval	Power Required	Array Area	Approximate Size
14 days	~23 kW	~115 m^2	~10 m × 12 m
3 days	~110 kW	~550 m^2	~23 m × 24 m
Daily fills	~334 kW	~1,670 m^2	~40 m × 42 m

A low-cadence LUNET node—one that serves a hopper every couple of weeks—can run its entire hydrogen production and liquefaction chain from approximately 115 m^2 of solar array, roughly comparable to a single ISS solar array wing and deployable from a single lander. As traffic grows, panels are added incrementally. The architecture scales linearly with demand.

Gaseous Hydrogen Alternative

An alternative worth consideration is gaseous hydrogen propulsion. The specific impulse penalty is approximately 10–15% compared to LH_2/LOX, but this eliminates the entire liquefaction chain and the cryogenic transfer problem. For short surface hops between LUNET nodes, this trade may close favorably: slightly more propellant per hop in exchange for dramatically simpler and more reliable node infrastructure.

5. Node Design Implications

The hydrogen infrastructure constraints and the water-as-network-commodity principle lead to specific design guidance for LUNET nodes:

- **Minimize LH_2 path length.** Electrolyzer, liquefier, and fill coupling should be co-located with the shortest practical plumbing run between them. A few meters, not tens of meters.
- **Minimize disconnect cycles.** Ideally a vehicle pulls up, receives a direct fill from on-site production, and departs. Intermediate bulk LH_2 storage with its own transfer plumbing should

be avoided where possible.

- **Stock seal consumables.** Indium gaskets, PTFE seal kits, and spring-energized seal replacements are standard logistics items at every node. This is part of the “logistics exchange” function.
- **Redundant fill lines at high-traffic nodes.** Line replacement on the lunar surface is a major operation. Parallel fill capability avoids single-point failures.
- **Boil-off monitoring as health telemetry.** Continuous boil-off rate measurement provides early warning of insulation degradation, enabling planned maintenance rather than reactive failure response.
- **Electrolyzer membrane spares.** PEM membranes have finite lifespans (typically thousands of hours). Periodic replacement is a planned maintenance activity.
- **Design for long life, not easy replacement.** All-welded construction with generous fatigue margins for permanent plumbing. Reserve disconnectable joints for planned service points only.

6. Resupply and Logistics Model

With node-level electrolysis and liquefaction, LUNET resupply simplifies to two categories:

Water delivery. Sourced from polar ISRU or from Earth as a backup. Delivered by simple unpressurized or low-pressure rovers and hoppers. No cryogenic handling, no vacuum-jacketed containers, no specialized transfer equipment.

Maintenance consumables. Electrolyzer membranes, cryogenic seal kits, power system maintenance items (solar array cleaning equipment, battery replacements), and diagnostic spares. These are compact, shelf-stable items that can be stockpiled.

This is a vastly more manageable logistics picture than transporting LH_2 across the lunar surface or maintaining a network of cryogenic transfer lines between nodes. LUNET converts the hardest problem in lunar propellant logistics—moving and storing liquid hydrogen—into the easiest one: moving and storing water.

7. Distributed vs. Centralized Architecture

LUNET’s distributed node concept is fundamentally more compatible with liquid hydrogen’s constraints than a centralized depot model. A central depot requires long transfer lines, large storage volumes, extensive plumbing with many disconnect cycles, and concentration of failure risk. LUNET’s “produce near, consume fast” approach minimizes all of these failure modes.

Key architectural advantages of the distributed approach:

- No long-distance LH_2 transfer lines to degrade and maintain
- No network-wide dependency on a single production facility
- Incremental growth: add nodes and solar capacity as traffic demands
- Redundancy through multiplicity rather than through parallel systems at a single point
- Each node is independently viable and independently maintainable
- Failure of one node degrades network capacity without halting operations