Why You Can't Ship Propellant to Jupiter

A Policy Brief on Cryogenic Supply Chain Feasibility for Outer Solar System Operations

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Bottom line: Of every 100 tonnes of cryogenic propellant dispatched from Earth toward Jupiter via relay chain, fewer than 3 arrive. This is not an insulation problem or a budget problem — it is a consequence of orbital mechanics and hydrogen thermodynamics that no relay architecture with passive cryogenic storage can overcome. NASA's Architecture Definition Document (ADD Rev 2, ESDMD-001) does not include commodity-resolved logistics screening, and the Mars ascent propellant strategy for the initial human Mars mission does not utilize ISRU-derived propellants (NTRS 20250003732). With DRACO's cancellation in FY2026, nuclear thermal propulsion — the only technology that could shorten transit times enough to partially address boiloff — is no longer in the development pipeline. The transit time floor is locked to chemical propulsion for the foreseeable planning horizon.

The Question

NASA's Moon-to-Mars architecture assumes a logistics pipeline extending from cislunar space outward. The question this brief addresses is narrow: **can cryogenic propellant be delivered through a relay chain to Jupiter?** Not whether it's expensive. Whether any hub along the route can stockpile enough propellant to keep the pipeline running. The answer is no.

The Numbers

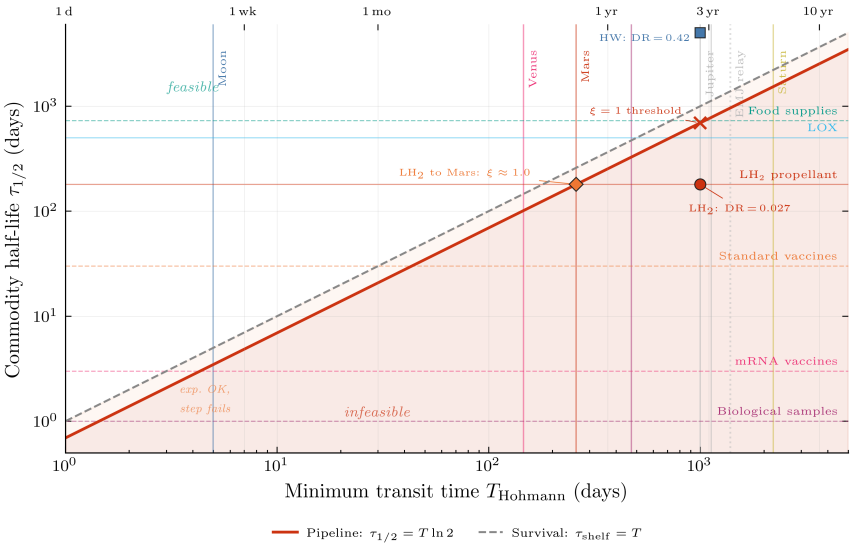

Figure 1: Commodity feasibility depends on two numbers: how long the cargo survives (vertical axis) and how long the trip takes (horizontal axis). Liquid hydrogen cannot survive any route beyond Mars. Hardware on the same route arrives at 42%.

Liquid hydrogen has a passive storage half-life of approximately 180 days in standard passive insulation. The Earth-Mars-Jupiter relay chain exposes cargo to cumulative boiloff across 7 hops totaling approximately 1,066 days — nearly six half-lives. To keep a Mars relay hub operational with 99% confidence at a 2.7% delivery ratio, you need **359 years** of continuous, uninterrupted propellant resupply — for a commodity that boils off in months. That is 168 Earth-Mars synodic cycles. Hardware on the same route, at a 41.8% delivery ratio, needs ~19 years.[1] The same infrastructure. The same routing. Two radically different outcomes, because different cargo types experience different attenuation at every hop.

[1]Reserve formula: R > ln(0.01) / ln(1 - DR), where DR is delivery ratio and 0.01 is the acceptable risk per resupply cycle. Methodology: TIN framework, 290,000+ configurations across 8 planetary bodies and 5 terrestrial contact datasets. Source code: https://github.com/toxic2040/TIN (AGPL-3.0). All inputs derived from publicly available ephemeris data and physical constants.

Why Engineering Cannot Close This Gap

Active cooling (Zero Boil-Off). NASA's Cryogenic Fluid Management program under STMD targets zero boiloff, but to date "cryogenic fuels have only been used for missions lasting less than a week" (NASA STMD). The multi-year durations required for Jupiter transit are orders of magnitude beyond current capability. Even if ZBO were demonstrated at interplanetary scale, it requires continuous power. At Jupiter (5.2 AU), solar flux is 1/27th of Earth orbit. Cooling multi-tonne propellant tanks requires megawatt-class power; available sources provide kilowatt-class. No power source in the current or projected pipeline bridges this gap.

Nuclear thermal propulsion. DRACO, the sole NTP development program, was cancelled in the FY2026 President's Budget Request. The budget's technical supplement stated that these programs "have not been identified as the propulsion mode for deep space missions." NTP was the only propulsion alternative that could shorten Mars-Jupiter transit below the boiloff sustainability threshold. Its cancellation locks the transit time floor to chemical Hohmann minimums (~1,127 days Mars-Jupiter) for the policy-relevant planning horizon.

The binding constraint. The relay chain analysis above uses a pre-positioned cycler vehicle for the Mars-Jupiter leg, shortening that coast to approximately 730 days. No such cycler infrastructure exists or is in the development pipeline. Without it, a direct chemical Hohmann transfer from Mars to Jupiter takes 1,127 days minimum — more than six LH2 half-lives on that single leg alone, before counting the Earth-to-Mars transit. This is Kepler's laws and Boltzmann's constant. No architecture redesign changes either.

NASA Already Recognizes the Gap

The ADD (Revisions 1 and 2) focuses on Human Lunar Return and Foundational Exploration stages where ISRU products are not utilized. Critically: the Mars ascent propellant strategy for the initial human Mars mission concept **does not utilize ISRU-derived propellants**, which led to the initiation in 2025 of joint STMD/ESDMD studies to define what, when, and how ISRU will be incorporated (NTRS 20250003732). ISRU development sits under STMD's Lunar Surface Innovation Initiative (LSII), within the "Live" thrust of the STAR framework. The first flight demonstration is LIFT-1 (targeting NET 2028). The organizational trajectory is pointed at the Moon — not at the outer solar system propellant boundary identified here.

Recommendations

1. Extend the scope of the joint STMD/ESDMD ISRU study (initiated 2025) to include commodity-resolved logistics feasibility for architectures beyond cislunar. The study currently addresses when and how ISRU will be incorporated. It should also address *where the cryogenic supply chain physically cannot reach.* The commodity phase diagram framework identifies feasibility boundaries by destination and cargo type using publicly available orbital mechanics and physical constants.

2. Require commodity-resolved logistics feasibility analysis as a KDP B gate product for missions with multi-hop propellant logistics. Current lifecycle reviews (NPR 7120.5) do not screen for commodity-dependent supply chain failure. A commodity feasibility assessment at Mission Concept Review or KDP B would catch physically impossible logistics assumptions before they consume development resources.

3. Direct STMD to include storable-propellant logistics assessment for outer solar system architectures within the LSII Domain and Capabilities restructuring. With DRACO cancelled and ZBO undemonstrated at interplanetary scale, the remaining options for Jupiter-class operations are: storable propellants (hydrazine, MON/MMH) with effectively infinite shelf life, or ISRU at Jovian moons using local ice deposits.
