

Competitive private nuclear thermal propulsion?

A technoeconomic and regulatory assessment

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NTR stage rendering

Commercialization is more credible than ever, but still challenging to concieve.

Technical & economic

- Collapsing launch costs (Starship) increase demand for in-space transport
- Chemical is nearing performance ceiling: LOX/LH₂ and methane already near thermochemical maximum.
- Lunar settlement geopolitics favor space nuclear, generally
- Rapid-response policing? Cislunar transit?

Relevant policy & strategic releases

- Dec 2025 Executive Order, *Ensuring American Space Superiority*
- NASA / DOE MOU (Jan 2026): lunar fission surface power by 2030
- 2024 Architecture Concept Review picks fission for Mars surface power
- DRACO cancelled (2025); “Freedom” (2026) revives space fission; China is pursuing NTP

But policy signals are neither consistent nor represent firm contracted demand.

NTP's physical advantage is simple. Its economics and regulation are the opposite.

Power from fission, rather than combustion, enables pure H_2 propellant, roughly **doubling specific impulse** at thrust similar to chemical:

$$v_e \propto \sqrt{T/M}, \quad \Delta v = g_0 I_{sp} \ln \frac{m_0}{m_f}$$

- Solid-core NTR: **830–1050 s** vs. **450–466 s** (LOX/LH₂) CITE
- The only higher- I_{sp} high thrust architecture
- Ground-test heritage: Rover/NERVA, >20 full-power tests

But I_{sp} is not everything.

Higher I_{sp} does not imply economic competitiveness. We ask

For which missions does NTP's advantage justify a premium development cost (probably $\geq 5\times$) and substantial regulatory burden? Privately?

Alternatives review

Architecture	I_{sp} (s)	Thrust	Primary limitation
Chemical (expendable)	450–462	High	I_{sp} ceiling; exponential mass growth
Chemical + refueling	450–462	High	depot infrastructure; orbital operations
Solid-core NTR	830–1050	Med–High	development cost; ground testing; regulatory
Nuclear electric	2000–10000+	Very low	multi-year transit; thrust/weight
Solar electric	1500–3000	Very low	power $\propto 1/r^2$; not feasible beyond Mars CITE

Refueled chemical is the near-term rival.

Our reference design: a reusable, licensable stage.

Design	Thrust kN	I_{sp} s	Mass kg
SNRE (Gen-1)	73	870	2,550
NERVA	337	825	12,300
HALEU (LEU)	97–140	867–900	2,200–3,700
Particle bed	48	1,050	1,840

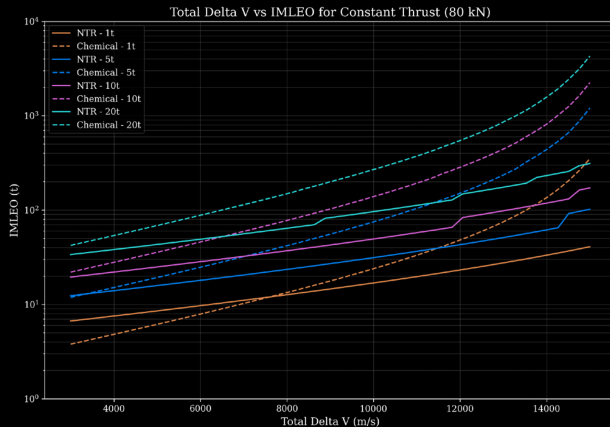
We target realistic SNRE-class, human-mission-class performance.

Design choices

- HALEU (19.75% enrichment)
- Reusable 2–5 flights; modular LH₂ drop tanks (?)
- Reactor start above ~1,100 km; 0.5–2 km/s disposal margin reserved
- Licensing-focused architecture

AMCM program cost $\approx$ \$1.9 B ($\sim 5\times$ chemical); the reactor/engine at TRL 4 drives $\sim 89\%$ of hardware cost.

Mass advantage only for high ΔV missions.



Initial mass to LEO vs. total Δv , constant 80 kN thrust

Advantage threshold when:

- Crossover for payloads **>5 t payload** or **>6 km/s**
- The margin *grows* with Δv

Below which a refueled chemical stage is preferable on a mass basis.

Value driver is likely maneuverability, not Mars (or anywhere aerobraking or refuelling are possible).

LEO→GEO	Δv	Time	Chem	NTR
20 t payload	km/s	hr	t	t
Hohmann (ref.)	3.9	5.26	52.9	37.8
Moderate	4.3	3.92	57.7	39.6
Fast (crew)	5.5	2.89	77.6	46.0
Very fast	7.2	2.22	120.1	57.5

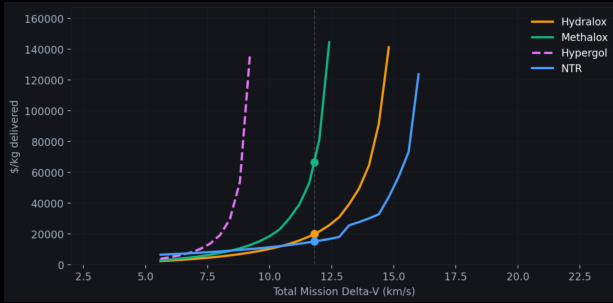
NTP is potentially faster *and* lighter: One NTR stage holds cumulative Δv for many burns. Chemical stage accordingly limited, unless refuelling possible.

A potential market is thus

One flexible stage that makes many burns (patrol, reposition, intercept) across a deployment.

DoD / Space Force might thereby pay a strategic premium? Nondilutively fund?

At high mission Δv s, NTR is eventually cheaper than chemical.



Fully amortized \$/kg delivered vs. total mission Δv

- At low Δv , chemical is cheaper per kg; NTR's overhead dominates
- NTR competitive past **$\sim 12\text{--}13\text{ km/s}$** for our reference design
- Reuse and cadence pull NTR curve down, as does refueling for chemical.

Ideally, price to the cost of alternative or willingness-to-pay ceiling.

NTP still has problems.

- **Mass:** probably an order of magnitude greater mass than chemical for same thrust
- **Control dynamics:** slower to start and stop than chemical
- **Xe-135 restart:** post-shutdown reactivity penalty prohibits restarting in the hours thereafter
- **Hot-channel margin:** localized overheating mandates careful design
- **Second shutdown mechanism:** control drums sufficient in all accident cases?
- **Cryogenic LH₂:** zero-boiloff is low TRL
- . . .

Sources: Eades, PhD, Ohio State (2016); Hoak, PhD, MIT (2026).

For the purposes of commercialization, two problems dominate:

Regulation, particularly of testing, and **market**, particularly future venture-scale demand.

The regulatory pathway is slow and atmospheric testing challenging to imagine.

Getting authorized

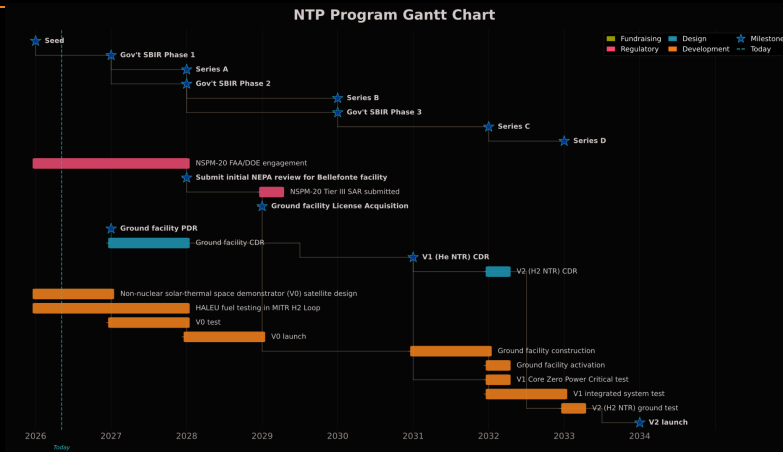
- NSPM-20 **Tier III** (space fission reactors): highest review tier, culminating in a Presidential finding of acceptability
- **No commercial pathway**: NRC Part 70 governs terrestrial facilities; FAA Part 450 defers to NRC; neither authorizes a commercial reactor operated in space
- Indemnification regime uncertain (to me)
- Near-term: a NASA / DoD prime files the Safety Analysis Report; the firm remains a *subcontractor*

The test problem

- A full-power hot-fire vents reactor-heated H₂, tritium, Kr-85, activated particulates
- NERVA tested open-air at Jackass Flats; now impermissible under EPA / NRC / state law (if accident scenarios considered), or certainly because of liability / public perception for a private actor.
- Needs an **effluent-capture facility** able to quench hot H₂, scrub, extract tritium, which has **never been built or licensed**. \$B?
- Permitting **≈ a decade (?)**: this, not the reactor, is the critical path

Moreover, requires **three sequential NEPA reviews**: programmatic EIS → ground-test-facility EIS → launch EIS.

Even supposing test facility constructed by another party, duration of the regulatory process protracts GANTTs, decimating IRRs.



Schedule consequence for a notional GANTT: reviews push the first nuclear ground test to *FY2034–37* and first flight beyond.

Moreover, near-term markets are small and future large markets poorly defined.

- Near-term demand is **small and government-concentrated** — a few institutional buyers for niche defense and science missions.
- Demand is concentrated close to Earth, where capacity for high Δv is less useful
- Where aerobraking or in-situ refueling are available, chemical competitive even for higher- Δv missions
- Asteroid mining a plausible long-term market, but timing uncertain.

Development CAPEX large enough to require a significant market, which is a struggle to define.

A private actor might resolve some of the agency problems that have challenged the public sector.

Why they stall

- No U.S. fission reactor flown since **SNAP-10A (1965)**
- Recurring causes: no sustained *mission pull*; **fragmented leadership**; overreach before readiness; timelines detached from decision cycles

Private actor might have the characteristics Lal describes.

- The “**Manhattan Project test**”: centralized authority, stable multi-year funding (?), sustained urgency, limited fragmentation

Sources: Lal, “Bold Goals Are Easy,” MIT (2026); Lal & Myers, “Weighing the Future,” INL (2023).

Conclusion: NTR needs a defined market and regulatory pathway to be commercialized. A private actor might act with more concentration.

1. NTR's advantage is **conditional**: for high cumulative Δv , rapid repositioning, and arrival where there is no aerobraking or in-situ refueling.
2. The near-term market is **cislunar and national-security maneuvers**, sold as responsiveness; resources / asteroid mining are possible long-term growth cases.
3. For a private firm the hard problems are **regulation, the schedule implied, and market served**; less the reactor.

Sources

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