

Electric Power Requirement for Surface Production of Return Propellant, and the Fleet-Size Crossover Between Fission and Fusion Surface Power

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KEYWORDS	in-situ resource utilisation; propellant production; Sabatier; electrolysis; fission surface power; fusion surface power; specific power; Mars; Moon

Abstract

This memorandum computes the electric energy and production capacity needed to make, on the Martian surface, the return propellant of one Starship-class vehicle, and compares the landed mass of fission and fusion power sources that could supply it at fleet scale. The chain is water electrolysis plus Sabatier methanation, with CO₂ acquisition, ice extraction, liquefaction and zero-boil-off storage. Result: ≈ 9.8 GWh of electricity per 1,200 t of CH₄/O₂ (4.6–16.9 GWh), requiring ≈ 0.96 MWe of production capacity per ship over a 500-day campaign at 85 % duty (≈ 0.82 MW time-averaged). At large fleet scale this becomes a hundreds-of-megawatts to gigawatt-class surface industrial load. Modular fission has no fixed fleet-size ceiling within the scaling model used. A fusion plant of the reference design class (850 MWe net, a design concept) supplies ≈ 890 ships per window and has lower landed mass than first-generation fission above ≈ 560 ships per window. Against MW-class fission no crossover exists within one plant's capacity unless the plant's precision structure is fabricated on site. On the Moon the return leg does not require fusion-class power at any cadence examined. All fusion figures are conditional on a device that has not been demonstrated.

Summary

Premise. No magnetic-confinement fusion device has produced more fusion energy than the heating power applied to its plasma. The fusion plant in this memorandum is a peer-reviewed design point, not built hardware, and its landed mass is an internal estimate. Every fusion figure below is conditional on both.

Question. How much electric power does it take to make the propellant for a return flight on a planetary surface, and at what fleet size does a fusion plant become the lighter way to supply it?

Method. Stoichiometry of the Sabatier and electrolysis chain with exact molar masses, published specific energies for each process step, division by the usable production time and duty factor, and comparison of landed power-source mass per ship refuelled. All tables are generated by one calculation script.

Results. One returning ship requires ≈ 9.8 GWh of electricity (4.6–16.9) and ≈ 0.96 MWe of production capacity at 85 % duty. At first-generation specific powers the power source and propellant plant together land ≈ 230 –275 t per returning ship, more than the ship's payload. A fleet of 1,000 ships per window requires ≈ 0.96 GWe of capacity. One reference fusion plant supplies ≈ 890 ships per window.

Negative results. Fusion is not required to return from Mars at any fleet size: modular fission can supply the same load by landing more units. Fusion has lower landed mass only against first-generation fission (0.0067 kWe/kg) and only above ≈ 560 ships per window (≈ 330 with replacement over five windows). Against MW-class fission (0.02–0.06 kWe/kg, two independent design studies, none built) no crossover exists within one plant's capacity unless its winding-pack plate is fabricated on site. The Moon's return leg does not require fusion-class power. Dust storms discriminate between solar and nuclear power, not between fission and fusion.

Nomenclature

m_p	propellant mass per returning ship, t
e_p	electric energy per unit propellant mass, kWh/kg
E_{ship}	electric energy per returning ship, GWh (electric)
t_w	usable production time per window, d
f_d	duty factor (fraction of t_w at rated output), dimensionless
P_{avg}	time-averaged electric load per ship, MW
P_{cap}	required production capacity per ship, MWe (P_{avg} / f_d)
s	landed specific power of a power source, kWe/kg
N^*	crossover fleet size, ships per window
r	fraction of installed fission mass re-landed per window
W	fusion wear-component mass re-landed per window, kt
w	window index, $w = 1$ for the installation window
LHV	lower heating value of hydrogen, 33.3 kWh/kg
FSP	fission surface power, 40 kWe reference unit class
ISRU	in-situ resource utilisation
LOX	liquid oxygen
O/F	oxidiser-to-fuel mass ratio
Window	one Earth–Mars synodic period, 780 d

1. Introduction

A vehicle that lands on Mars and returns must obtain its return propellant on the surface or carry it. For a Starship-class vehicle the published plan requires full propellant tanks for the return, produced locally. Production of that propellant is an electrical load. This memorandum sizes that load per ship and at fleet scale, and determines which surface power source supplies it at the lowest landed mass.

Scope. Mars surface is the primary case. The lunar surface is examined as a variant. Power sources compared: fission at two specific-power classes, a fusion plant of the reference design class, and solar power with and without storage.

Context. In December 2024 NASA selected nuclear fission as the primary surface power technology for crewed Mars missions, citing robustness through global dust storms and advantages in landed mass and volume, and stated that architectures with propellant manufacturing could require megawatt-class power [18]. A 2025 NASA plant model producing 30 and 300 t of CH₄/O₂ per Mars year found that fission surface power traded better than solar arrays with batteries, that the power system is 34–59 % of plant landed mass, and that electrolysis draws 53–62 % of plant power [19]. This memorandum was computed independently of [19]; it extends the comparison to fleet scale and to a fusion design point.

Excluded. Currency costs. Outbound propellant. Orbital refuelling. Start-up power of the fusion plant itself. Propellant production in orbit. Any statement about when any of this occurs.

Maturity of the power sources compared. First-generation fission: a programme design requirement; the only tested unit of its lineage is a ground test at ≈ 1 kW_e [15]; none has flown. MW-class fission: values from two independent design studies [16][17]; none built or tested. Fusion plant: a peer-reviewed design concept; no device of its kind exists. Solar with storage: study values. None of the four is flight-proven at the scale considered.

2. Method

Chemistry. Water is electrolysed ($2 \text{ H}_2\text{O} \rightarrow 2 \text{ H}_2 + \text{O}_2$). Hydrogen reacts with atmospheric CO₂ in a Sabatier reactor ($\text{CO}_2 + 4 \text{ H}_2 \rightarrow \text{CH}_4 + 2 \text{ H}_2\text{O}$, exothermic, -165 kJ/mol) [13]. The Sabatier water is returned to the electrolyser. Molar masses: H₂ 2.016, CH₄ 16.043, H₂O 18.015, CO₂ 44.010, O₂ 31.999 g/mol.

$$E_{\text{ship}} = m_p \cdot e_p \quad e_p = \sum e_i \quad (1)$$

$$P_{\text{avg}} = E_{\text{ship}} / (t_w \cdot 24 \text{ h}), \quad P_{\text{cap}} = P_{\text{avg}} / f_d \quad (2)$$

$$m_{\text{source per ship}} = P_{\text{cap}} / s \quad (3)$$

$$N^* = M_{\text{fusion}} / (P_{\text{cap}} / s_{\text{fission}}) \quad (4)$$

$$N^*(w) = [M_{\text{fusion}} + W(w - 1)] / [(P_{\text{cap}} / s_{\text{fission}})(1 + r(w - 1))] \quad (5)$$

Equation (4) gives the fleet size at which the landed mass of multiplied fission units equals the landed mass of one fusion plant at installation. Equation (5) adds the replacement streams of both options up to window w . "Five windows" means $w = 5$: the installation window plus four subsequent windows. Replacement is treated as a continuous rate: $r = 780 \text{ d} / (10 \text{ yr} \cdot 365.25 \text{ d}) = 0.2136$ for a 10-year fission life, and $W = \text{wear rate} \times 780 \text{ d} / 365.25 \text{ d}$ for the fusion plant. Sizing uses P_{cap} , because a power source must be rated for its output while operating, not for its time average. The band of E_{ship} is computed from two explicit corner cases (Section 5). Results are cross-checked against five published estimates not derived from this calculation (Table 3).

3. Assumptions

1. **A1.** Return propellant 1,200 t CH₄/O₂ at O/F 3.6, the published full-tank figure [2]. Sensitivity 800–1,500 t. A rocket-equation floor of $\approx$ 400–800 t exists below this band. [M]
2. **A2.** Electrolysis at 55.5 kWh per kg H₂ (60 % of LHV), from a published PEM system value of 55.2 kWh/kg [7]. Sensitivity 44.4–66.7 kWh/kg (75–50 % LHV). Stack type: low-temperature PEM, all heat supplied electrically. The NASA 2025 plant model uses solid-oxide electrolysis [19], which shifts part of the demand to heat; that variant is not modelled here. [M]
3. **A3.** Sabatier water fully recycled; Sabatier heat credited only against thermal loads it can displace. [P]
4. **A4.** Usable production time 500 d per window, duty factor 0.85. Basis: 470 d usable in [2]; 420–750 d depending on opportunity in [4]. Sensitivity 300–600 d; 780 d for a steady-state plant. [E]
5. **A5.** First-generation fission: a programme design requirement of 40 kWe per unit at $\leq$ 6,000 kg and 10-year life, giving 0.0067 kWe/kg [5]. Not flown; not demonstrated at this rating. [M]
6. **A6.** MW-class fission: 0.02–0.06 kWe/kg, bracketed by two independent design studies: 0.026 kWe/kg (near-term) to 0.053 kWe/kg (advanced) for a 500 kWe surface system with crew-rated shielding [16], and 0.0625 kWe/kg for a 2 MWe surface system with modest shielding [17], the value quoted in [2]. Design values; no MW-class fission system has been built. [M]
7. **A7.** Fusion plant: 850 MWe net (780–930) and 80 kt landed (67–119), from the organisation's internal mass and heat-balance computations of a peer-reviewed design point [11][12]. The ratio, 0.0106 kWe/kg, is arithmetic; the landed mass is the uncertain quantity. Conditional on the premise in the Summary. [C]
8. **A8.** Fusion import tiers when bulk mass is produced on site: 33 kt (plates imported, coils wound on site) and 18.6 kt (plates also fabricated on site) [12]. Internal, conditional. [C]
9. **A9.** Replacement: fission 10-year life ($r = 0.214$ per window); fusion wear stream 0.8–1.2 kt per year (1.71–2.56 kt per window) [12]. [E]
10. **A10.** Moon: no demonstrated lunar carbon resource suitable for industrial-scale methane production is assumed, so a CH₄/O₂ vehicle makes only its LOX locally and CH₄ is imported. Lunar surface to near-rectilinear halo orbit 2,650 m/s [1]. [A]
11. **A11.** Mars solar power with storage, system level 0.003–0.010 kWe/kg [12]. [E]
12. **A12.** All thermal loads (ice melting, sorbent regeneration) are supplied electrically. This is conservative; Sabatier heat is credited separately. [A]

! DESIGN VALUES — A6 is bracketed by two independent studies but describes hardware that has not been built. It is the input with the largest effect on the crossover (factor up to 9, Section 5).

4. Results

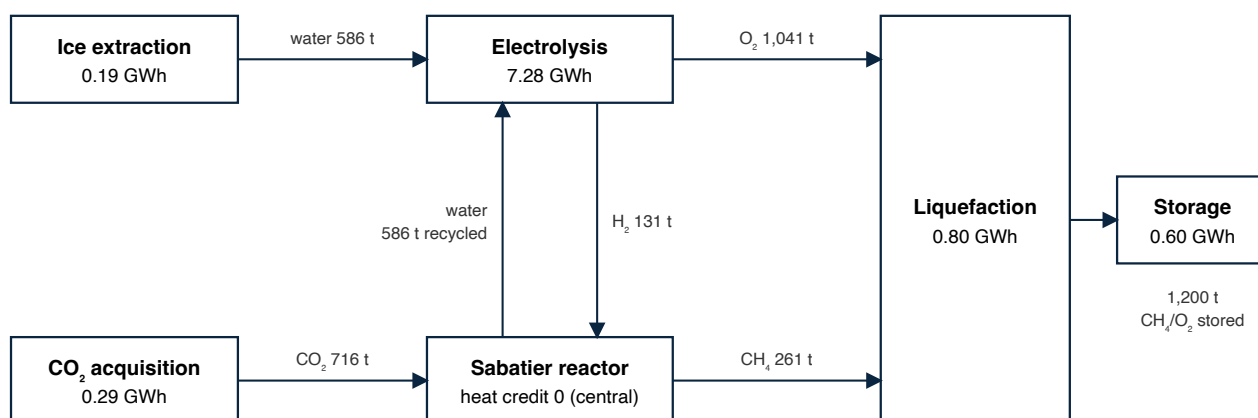
4.1 Feedstock per returning ship

Table 1. Feedstock and products per 1,200 t of CH₄/O₂ propellant (exact molar masses).

Quantity	Mass, t	Tag
Methane / oxygen in propellant	260.9 / 939.1	[C]
Hydrogen required	131.1	[C]
Water electrolysed	1,171.8	[C]
Water returned by Sabatier	585.9	[C]
Net water extracted	585.9	[C]
CO ₂ captured	715.6	[C]
O ₂ produced (surplus over requirement)	1,040.7 (101.5)	[C]

Source: calculated, this document [12], from A1 and A3. Integer molar masses give CO₂ 717 t and O₂ 1,043 t; the exact values above are used.

4.2 Electric energy per ship



Overhead 0.64 GWh · Total 9.79 GWh per ship (8.16 kWh/kg) · O₂ surplus 102 t

Figure 1. Process flow for one returning ship, central case: mass flows and electric energy per step.

Source: calculated, this document [12]; values as in Tables 1 and 2.

Table 2. Electric energy per returning ship by process step (central case).

Step	Basis	GWh	Tag
Water electrolysis, 131.1 t H ₂	55.5 kWh/kg H ₂ [7]	7.28	[C]
CO ₂ acquisition, 716 t	0.4 kWh/kg; isothermal floor 0.057 kWh/kg	0.29	[E]
Water extraction from ice, 586 t	0.32 kWh/kg = 0.27 kWh/kg heat (twice the 0.134 kWh/kg melt minimum, supplied electrically, A12) + 0.05 kWh/kg pumping and purification	0.19	[E]
Liquefaction, O ₂ and CH ₄	0.6 and 0.9 kWh/kg; small-scale value 2.4 kWh/kg [8]	0.80	[E]
Zero-boil-off storage	6.655 kW for 29.7 t [4], scaled by mass ^(2/3) to 78 kW; 12,000 h; average fill 0.64	0.60	[E]
Sabatier heat credit	central case 0; full credit -3.6 %	0.00	[C]
Overhead	7 % of the subtotal	0.64	[E]
Total	8.16 kWh per kg propellant	9.79	[C]

Source: calculated, this document [12]; step bases as cited. Electrolysis is 74 % of the total. Band 4.6–16.9 GWh from the corner cases in Table 9.

Table 3. Independent published estimates of electric energy per kg of propellant.

Source	Case	kWh/kg	Tag
Miyajima 2023 [1]	1,040 kW for 938 t/yr	9.7	[M]
Maiwald et al. 2024 [2]	2,400 t in 470 d at 3.06–3.37 MW	14.4–15.8	[M]
Kleinhenz and Paz 2017 [3]	29.7 t in 480 d; excluding regolith heating	13.6 (20)	[M]
Zubrin and Baker 1991 [6]	imported H ₂ ; lower bound, not comparable	6.8	[M]
Rucker et al. 2016 [4]	LOX only, solid-oxide electrolysis	9.0	[M]

Source: references as listed. None derived from Table 2.

The value of 8.2 kWh/kg lies at the plant-scale end of the published range [C]. Small-scale hardware estimates are higher by a factor of 1.7–2.5 [M]. The upper band value of 16.9 GWh covers first-generation hardware [C].

The NASA 2025 plant model [19] publishes shares, not energy per kilogram. Its electrolysis share, 53–62 % of plant power, is lower than the 74 % here because solid-oxide electrolysis uses heat in place of part of the electricity [M]. Its power-system share of landed mass, 59 % at 300 t per Mars year, is consistent with Section 4.4, where the power source outweighs the propellant plant at first-generation specific powers [M].

4.3 Load and required capacity per ship

Table 4. Required production capacity P_{cap} per ship, MWe, by energy per ship and usable production time (duty factor 0.85).

E_{ship}	300 d	500 d	600 d	780 d	Tag
4.6 GWh (low corner)	0.76	0.45	0.38	0.29	[C]
9.8 GWh (central)	1.60	0.96	0.80	0.62	[C]
16.9 GWh (high corner)	2.77	1.66	1.38	1.06	[C]

Source: calculated, this document [12], equation (2).

At the central case the time-averaged load is 0.82 MW and the required production capacity is 0.96 MWe per returning ship [C]. Published values of 1.04 MW [1] and 1.69 MW with margin [2] lie within the band [M]. A fleet of 1,000 ships per window requires ≈ 0.96 GWe of capacity (0.45–1.66 across the energy band at 500 d) [C].

4.4 Fission power per ship and at fleet scale

Table 5. Landed fission mass required, by specific-power class and fleet size.

Class	Per ship	100 ships	500 ships	1,000 ships	Tag
First generation, 0.0067 kWe/kg (design requirement)	144 t	14.4 kt	72 kt	144 kt	[C]
MW class, 0.02 kWe/kg (design study)	48 t	4.8 kt	24 kt	48 kt	[M]
MW class, 0.06 kWe/kg (design study)	16 t	1.6 kt	8.0 kt	16 kt	[M]

Source: calculated, this document [12], equation (3), from A5 and A6 [5][16][17].

Modular fission has no fixed fleet-size ceiling within this scaling model [C]. Capacity is added by landing further units: 24 first-generation units per ship per window [C]. The real constraints are landed mass and landing count, together with radiator area, unit spacing, shielding, maintenance and electrical distribution, which this memorandum does not size. The reactors for a 1,000-ship window at first-generation specific power correspond to $\approx 1,900$ cargo landings of 75 t [C]. The propellant plant itself adds 90–130 t per ship at linear scaling [1][2] [M].

4.5 Fusion plant capacity and crossover

Table 6. Ships per window supplied by one 850 MWe fusion plant (P_{cap} basis, duty 0.85).

Usable time	E = 9.8 GWh	E = 16.9 GWh	E = 4.6 GWh	Tag
300 d	530	310	1,120	[C]
500 d	890	510	1,870	[C]
600 d	1,060	610	2,250	[C]
780 d	1,380	800	2,920	[C]

Source: calculated, this document [12], from A4 and A7. Conditional on the premise in the Summary.

Table 7. Crossover fleet size N^* , ships per window, at which one fusion plant has lower landed mass than multiplied fission (central energy, 500 d).

Fusion mass basis	vs 0.0067 kWe/kg	vs 0.02 kWe/kg	vs 0.06 kWe/kg	Tag
Landed whole, 80 kt, eq. (4)	560 (280–990)	1,670	5,000	[C]
Import tier 1, 33 kt, eq. (4)	230	690	2,060	[C]
Import tier 2, 18.6 kt, eq. (4)	130	390	1,160	[C]
Landed whole, with replacement to $w = 5$, eq. (5)	330 (330–340)	1,000	—	[C]

Source: calculated, this document [12], equations (4) and (5), from A5–A9. The range on the first row spans plant mass 67–119 kt and usable time 300–600 d. The range on the last row spans the fusion wear stream of A9. Fusion mass basis is internal and conditional.

One plant supplies ≈ 890 ships per window [C]. A crossover above that number means the plant is fully subscribed before it becomes lighter than the fission alternative [C]. Against MW-class fission this is the case across the whole band 0.026–0.0625 kWe/kg unless import tier 2 is achieved [C]. If the fusion wear stream is omitted from equation (5), the five-window crossover against first-generation fission falls to ≈ 300 ships [C].

! CONDITIONAL — Import tier 2 requires 14.9 kt of winding-pack plate to be machined and wound on the surface. This has not been done anywhere off Earth. Its feasibility is an open question in the organisation's research queue.

Ordering. First-generation fission supplies capacity with each landed unit [C]. A fusion plant supplies nothing until it and its coil-fabrication facility, with a 2–3 kt fission pre-power supply, are landed and operating [12] [C]. Fission therefore supplies the return leg for the first several hundred ships regardless of the crossover.

Table 7a. Fusion plant landed-mass basis and derating chain, Mars surface (internal report 034; conditional on the design point [11]).

Component	Mass, kt	Tag
48 HTS coils (winding packs incl. SS316 radial plates)	16.2	[P]
Coil casings + inter-coil support structure	12 (8–16)	[E]
Breeding blanket (WCLL, 86 % PbLi by mass)	4.3	[E]
First wall + divertor targets	0.3	[E]
In-vessel neutron shield (WC-based)	4 (3–4.5)	[E]
Vacuum vessel	2.5	[E]
Cryostat + thermal shield + feeders	3.5	[E]
ECRH heating system	0.8	[E]
Cryoplant (20 K)	0.8	[E]
Balance of plant (turbines, steam generators, pumps, electrical, tritium plant)	10	[E]
Radiator field, Mars, radiator at 40–80 °C (corrected in Rev F)	25 (12–64)	[C]
Total (all components at their low / high ends)	79.4 (61–123)	[C]

Source: internal report 034 [12], radiator field corrected by internal report 055 [12]; coil masses from [11] Table 8; other components estimated from the radial build of [11] and ITER analogies. The 67–119 kt band of A7 is report 034's combined estimate; the wider bracket assumes every component at its extreme at once.

Derating: 2,700 MW fusion and 3,150 MW thermal [11] give 1,054 MWe gross on Earth and 871–1,018 MWe gross on Mars at radiator temperatures of 40–80 °C; the plant's own loads (coolant pumping, cryoplant, controls) take ≈ 90 MW, leaving 780–930 MWe net, 850 MWe central [C].

4.6 Dust storms

Global dust storms recur about once per 2.5 windows and last 2–3 months, with optical depth 5–10 [10] [M]. The 2018 storm reduced solar array output by 96.7 % [10] [M]. Both nuclear options are unaffected [P]. Propellant production is deferrable and storable. A 120-day storm at 35 % output inside a 500-day window costs 15.6 % of production [C]. Solar power is therefore derated and exposed to a missed-window risk, not excluded. This result does not discriminate between fission and fusion.

4.7 Moon variant

Table 8. Lunar return leg: required capacity and landed power-source mass by cadence (LOX 102–227 t per leg, 10.8 kWh/kg, duty 0.85).

Return legs per year	10	100	1,000	Tag
Required capacity, MWe	1.5–3.3	15–33	147–329	[C]
First-generation fission, kt	0.22–0.49	2.2–4.9	22–49	[C]
MW-class fission, kt	0.025–0.16	0.25–1.6	2.5–16	[M]
Polar solar, 0.03–0.05 kWe/kg system level, kt	0.029–0.11	0.29–1.1	2.9–11	[E]
Fusion plant, 80 kt, 0.010 kWe/kg, kt	80	80	80	[C]

Source: calculated, this document [12], from A10 and [9]. Energy per leg 1.1–2.5 GWh. Fusion mass internal and conditional.

Fusion-class power is reached only at $\approx 1,000$ return legs per year [C]. At that cadence polar solar and MW-class fission have lower landed mass than the fusion plant by factors of 5–27 [C]. The imported CH₄ stream is 28–63 t per leg regardless of power source [C]. Earth-delivered propellant remains a competitor to lunar ISRU itself [1] [M].

5. Sensitivity

Table 9. Effect of each input on energy per ship and on the crossover N* against first-generation fission, ranked.

Input	Range	Effect	Tag
MW-class fission specific power	0.0067–0.06 kWe/kg	$N^* \times 9.0$ (560 $\rightarrow$ 5,000); decides whether a crossover exists	[M]
Fusion import tier	80 $\rightarrow$ 18.6 kt	$N^* \times 4.3$ (560 $\rightarrow$ 130)	[C]
Propellant per ship	800–1,500 t	E_{ship} 6.59–12.18 GWh; N^* 830–450	[C]
Electrolyser efficiency	50–75 % LHV	E_{ship} 11.36–8.23 GWh	[C]
Usable production time	300–600 d	P_{cap} 1.60–0.80 MWe ($\times 2$); N^* 330–670	[C]
Sabatier heat credit	0–100 %	E_{ship} -3.6 %; negligible	[C]
Corner cases for the band	low: 800 t, 44.4 kWh/kg H ₂ , CO ₂ 0.2, water 0.184, liquefaction 0.4/0.6 kWh/kg, storage 0.3 GWh, overhead 5 %, full Sabatier credit · high: 1,500 t, 66.7, CO ₂ 0.8, water 0.586, liquefaction 1.2/1.6, storage 1.2 GWh, overhead 10 %, no credit	E_{ship} 4.63–16.94 GWh	[C]
Solar with storage as rival	0.003–0.010 kWe/kg	96–320 t per ship; loses to fusion above 250–830 ships per window	[E]
Solar without storage, deferrable load	0.005–0.009 kWe/kg average	107–192 t per ship; loses to fusion above 420–750	[E]

Source: calculated, this document [12]. Solar bounds anchored by the two published cases in [4]: solar lighter by $\times 2.4$ for a deferrable demonstrator, fission lighter by $\times 1.9$ for a crewed load through a 120-day storm.

The three inputs with the largest effect are the specific power of MW-class fission, the fusion import tier, and the product of propellant load and electrolyser efficiency ($\times 2.5$ combined) [C].

6. Discussion

Per ship, the power source and propellant plant for a return flight have a landed mass comparable to or larger than the ship's payload. At this level the return is limited by surface energy supply before it is limited by the vehicle. With MW-class fission the ratio falls, and energy becomes comparable to, rather than larger than, the vehicle constraint.

At large fleet scale, Mars return-propellant production becomes a hundreds-of-megawatts to gigawatt-class surface industrial load. It is the largest surface electrical load identified in the sources reviewed. The capacity of one

reference fusion plant matches the published fleet ambition of 1,000 ships per window [14]. This is a coincidence of scale and decides nothing.

The claim that fusion is required for return from a planetary surface is not supported. Modular fission can supply the same load and may remain the lower-mass option, depending on future reactor specific power and on the degree of on-site fusion-plant fabrication. Fusion offers lower landed mass only if the fission alternative remains near first-generation specific power, or if the fusion plant's precision structure is produced on site. Both conditions are open. On the Moon neither applies, because the load stays below fusion's class at every cadence examined.

The dust-storm argument applies against solar power. It does not favour fusion over fission; both are nuclear heat sources independent of irradiance.

7. Limitations

1. No magnetic-confinement fusion device has shown net fusion gain. All fusion figures inherit design-target status from the reference design point [11] and the organisation's internal computations [12].
2. The fusion plant mass, power and wear figures come from internal reports that have not been externally reviewed. The landed mass, not the arithmetic, dominates the fusion uncertainty.
3. MW-class fission specific power rests on two independent design studies [16][17]; no such system has been built. It is the most sensitive input.
4. First-generation fission specific power is a programme requirement; the tested anchor is a ≈ 1 kWe ground test [15].
5. Propellant per ship is a published plan figure; a rocket-equation floor of $\approx 400\text{--}800$ t lies below it.
6. Siting constraints of multiplied fission (radiator area, unit spacing, shielding, distribution) are not sized.
7. No mass-growth allowance is applied to either option; the NASA 2025 model applies AIAA S-120A-2015 allowances [19]. A uniform allowance cancels in equation (4); maturity-dependent allowances, larger for the less mature fusion plant, would raise N^* .
8. Carbon-bearing lunar volatiles are not reviewed; their industrial usability is outside scope (A10).
9. Currency cost: NOT AVAILABLE. Not computed.
10. Start-up power for the fusion plant is excluded. It is under separate study.
11. Propellant-plant scale economies are not credited beyond a stated estimate (30–60 t per ship at power-law scaling).
12. One external cross-model review has been received and dispositioned (Revision Record). No human peer review.

8. Conclusions

1. Producing the return propellant of one 1,200 t CH_4/O_2 ship on Mars requires ≈ 9.8 GWh of electricity (4.6–16.9) and ≈ 0.96 MWe of production capacity at 85 % duty over a 500-day campaign (Tables 2, 4).
2. At first-generation specific powers the landed power source and propellant plant exceed the ship's payload per returning ship (Section 4.4).
3. At large fleet scale the return leg is a hundreds-of-megawatts to gigawatt-class surface industrial load (Section 4.3).
4. Modular fission can supply any fleet size within the scaling model. Fusion is never the only source that closes the return leg (Table 5).
5. One reference fusion plant supplies ≈ 890 ships per window (Table 6), conditional on an undemonstrated device.

6. Fusion has lower landed mass than first-generation fission above ≈ 560 ships per window, ≈ 330 with replacement to the fifth window (Table 7).
7. Against MW-class fission, no crossover exists within one plant's capacity unless the plant's winding-pack plate is fabricated on site (Table 7). This holds across the two-sourced band of design values; no MW-class fission system has been built.
8. The lunar return leg does not require fusion-class power at any cadence examined (Table 8).
9. Dust storms discriminate between solar and nuclear power, not between fission and fusion (Section 4.6).

References

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Revision Record

Revisions.

Rev	Date	Change	Author
A	2026-09-27	Initial issue, draft for external review. Computation basis: internal report 049.	E. Lupo; D. Wolf
B (v1.1)	2026-09-27	External cross-model review dispositioned (internal record 053). Accepted: capacity versus time-averaged load defined (P_{cap} , P_{avg}); 0.06 kWe/kg fission row corrected (15 → 16 t per ship) and all dependent crossovers recomputed; replacement crossover given as equation (5); "no physical ceiling" replaced by model-bounded wording; lunar carbon statement replaced by an assumption; maturity of each power source stated; conclusions reworded. Rejected with reason: CO ₂ 717 t and O ₂ 1,043 t (integer molar masses; exact values retained); water-extraction factor applied twice (the factor 2 is already inside 0.27 kWh/kg; wording clarified); five-window crossover 240–270 (omits the fusion wear stream; ≈ 330 retained, equation shown). Found in recomputation: water electrolysed 1,173 → 1,172 t; energy band 4.8–16.7 → 4.6–16.9 GWh from explicit corners; propellant-load sensitivity of N* 270–890 → 450–830; window range of N* restated for 300–600 d; lunar capacity and mass rows recomputed. All tables now generated by the calculation of record.	E. Lupo; D. Wolf
C (v1.2)	2026-09-27	A6 two-sourced (internal record 054): origin of the single value traced to [17]; independent second source [16] added. Band 0.02–0.06 kWe/kg retained; tag changed from single-source to published design values; conclusions unchanged across the band. No number changed.	E. Lupo; D. Wolf
D (v1.3)	2026-09-27	Transparency revision after a second cross-model review of the public record. Added: NASA 2024 surface-power decision and NASA 2025 plant model as context and comparison [18][19]; electrolyser stack type stated (A2); Figure 1 process flow with energy per step; Table 7a fusion plant mass basis and derating chain (internal report 034, conditional); mass-growth allowance limitation; calculation script published. No result changed.	E. Lupo; D. Wolf
E (v1.4)	2026-09-27	Source preservation: every cited open source archived locally with a SHA-256 fingerprint (17 of 18; [10] paywalled, not copied). Open NASA copies added for [8] and [15]; the OSTI address for [15] was unreachable on 2026-09-27. No number changed.	E. Lupo; D. Wolf
F (v1.5)	2026-09-27	Upstream correction (internal report 055): the Mars convective coefficient behind the fusion plant's radiator field was ≈ 10× too high for metre-scale panels. Radiator field 15 (7–30) → 25 (12–64) kt; fusion plant landed mass 70 (62–85) → 80 (67–119) kt (A7, Table 7a). Recomputed: crossover vs first-generation fission ≈ 490 → ≈ 560 ships per window (330 with replacement); vs MW-class fission unchanged in class (no crossover within one plant's capacity without import tier 2); solar-with-storage crossover 250–830. Import tiers, energy and power per ship unchanged. No conclusion changed class.	E. Lupo; D. Wolf
G (v1.6)	2026-10-23	Calculation of record cited by its published name [12]; Table 7a radiator-field row labelled "corrected in Rev F" in place of an internal file reference; comments of the published script reworded. No number changed.	E. Lupo; D. Wolf

Source: document control; review disposition in internal record 053; sourcing in internal record 054.