Roadmapping Research on Warming Mars: The Ultimate In-Situ Resource Utilization Challenge

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Can We Create Sustainable Habitats and Biospheres Beyond Earth?

Here we present a roadmap for researching the feasibility of warming Mars using technologies that exist today or could exist in the near future with reasonable development efforts. A 2025 National Academies consensus report prioritizes an "integrated ecosystem of plants, microbes, and animals" to support initial human missions and inform future choices about Mars resource utilization [1]. A first step towards creating sustainable biospheres on Mars is increasing the surface temperature either locally or globally. With a warmed habitat, genetically engineered microbes can survive on the surface of Mars and usher in biogeochemical cycling in support of sustained human operations. This research aims to characterize potential climate feedbacks and end states, bound mission requirements for full scale deployment, and increase the Technology Readiness Level of dependent technologies [2].

This is a summary. For details, see:

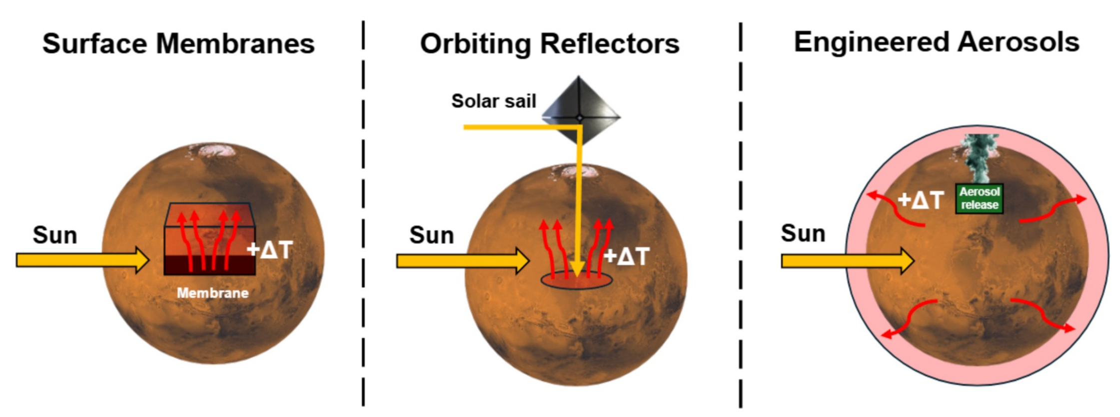

Fig. 2: Simplified schematic of three Mars-warming methods. Mars can be warmed by adding sunlight (orbiting reflectors), or an insulating blanket made either of solids (membrane warming approach) or aerosol in the atmosphere [1].

	Solid-state greenhouse membranes	Orbiting reflectors	Engineered aerosols	
			Air as feedstock	Soil/rocks as feedstock
Would it warm Mars?	Yes	Yes	Maybe	Yes
Maturity	Low	Relatively high	Relatively high upstream, low downstream	Low
Supports a 1,000 person base?	Yes	Probably	Synergizes with, but does not directly support	Over-engineered for this purpose
Scalability to >10^6 km^2 of warmed area?	No	Enhances (via pressure increase)	Yes	Yes
Synergy with human needs	Yes	Plausible but unproven	Yes	Over–produces metals
35 K warming achievable given 0.3-3 bn/K/yr cost tolerance?	Only for <<10^6 km^2 areas, without exponential production of warming membranes	No, unless spacecraft are made at Mars' moons	Yes for medium cost tolerance, but major uncertainties in radiative efficiency and particle lifetime	Yes for medium cost tolerance, but major uncertainties in particle lifetime and manufacturing scale-up
Power needed	<< 1 GW	N/A	~500 MW for ~5 K warming	~1 GW for ~5 K warming
Mass arriving at Mars	3000 tonnes/km^2 (for aerogel)	1×10^4 tonnes @10 g/m^2 for 10^3 km^2	2×10^4 tonnes excluding power system, ~5 K warming	1×10^4 tonnes excluding power system, ~5 K warming
Risk associated with uncertainties in physical/chemical properties/processes	Relatively low	Relatively low to medium	High	High

Table 1: Terraforming A La Carte. See [1] for details

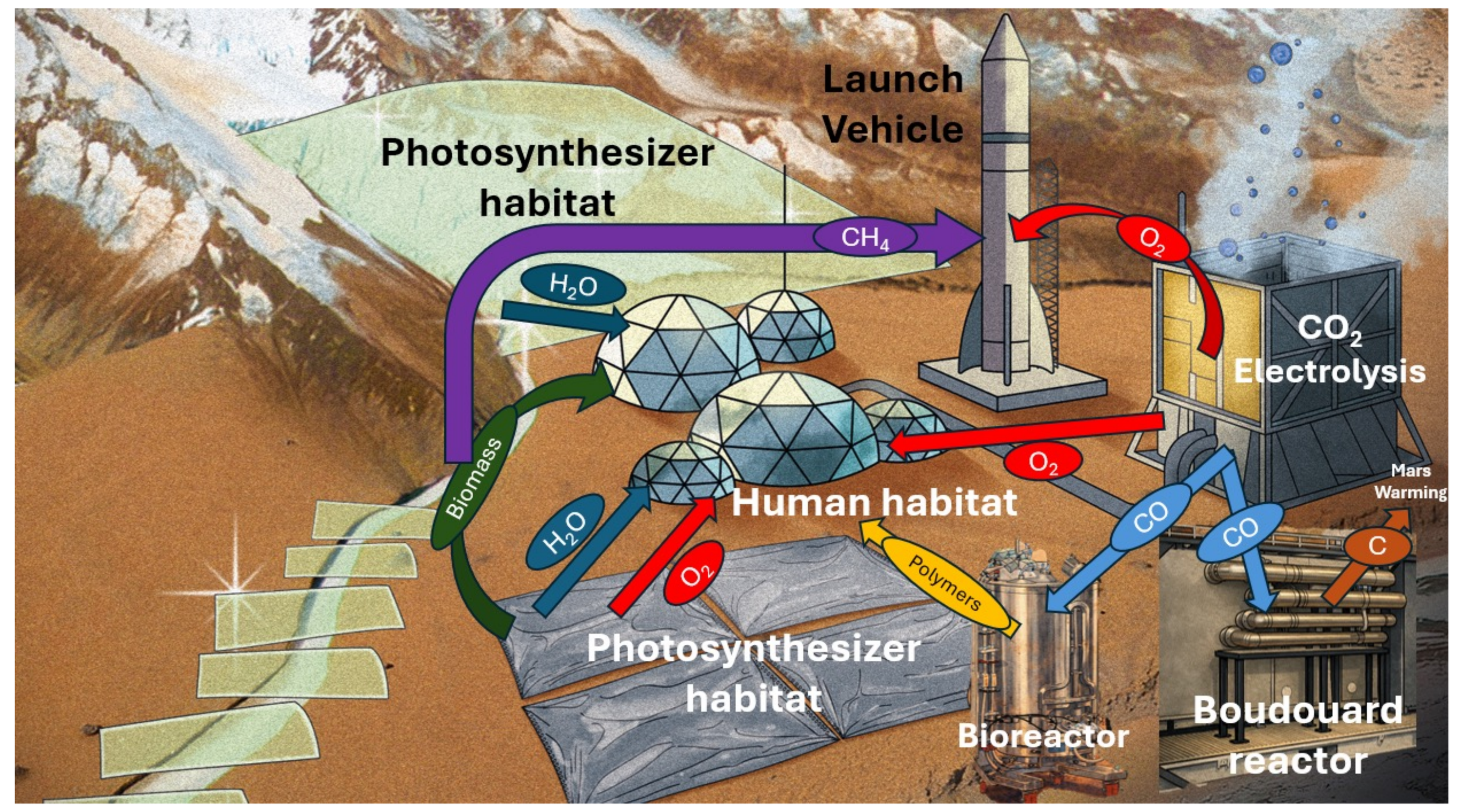

Fig. 3: Example synergies between a human habitat, a microbial habitat, a scaled-up version of the MOXIE experiment, a carbon factory and a launch vehicle [1].

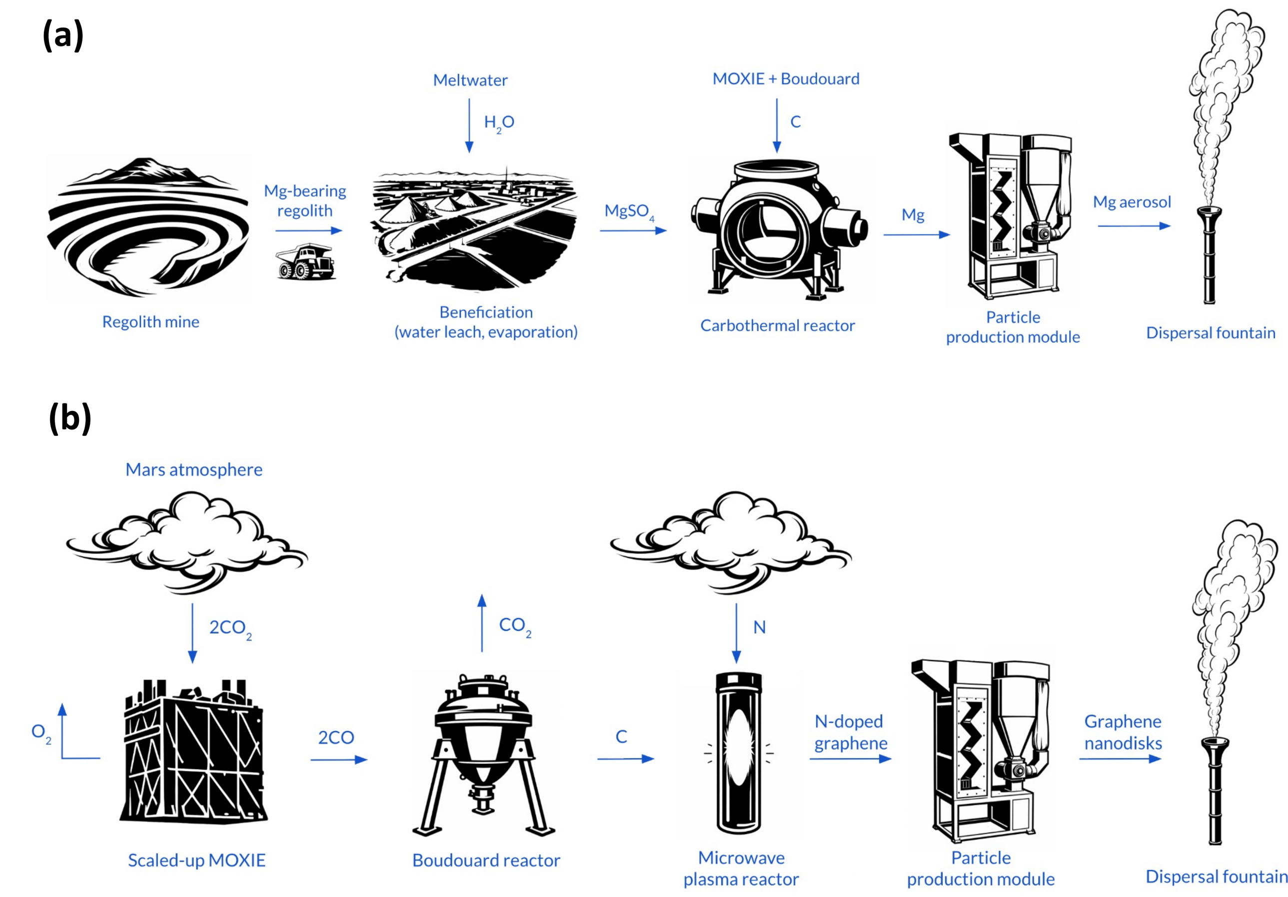

Fig. 4: Concept of operations sketches for warming Mars using (a) air as feedstock, or (b) using soil and rocks as feedstock [1].

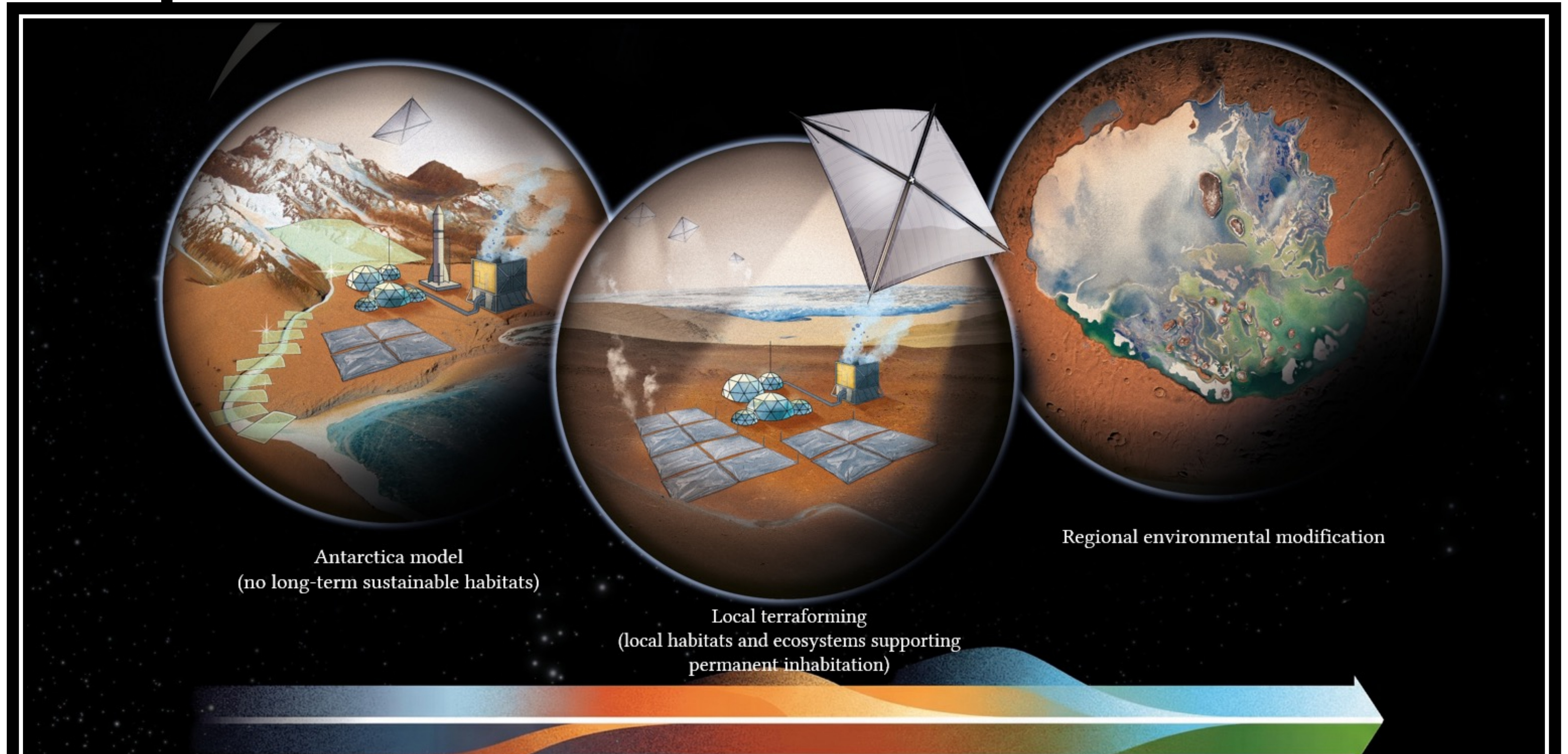

Fig 1: Possible human-involved futures for Mars may include the Antarctica Model, local terraforming, or regional-to-global environmental modification. Proposed research to address outstanding questions for each of these methods.

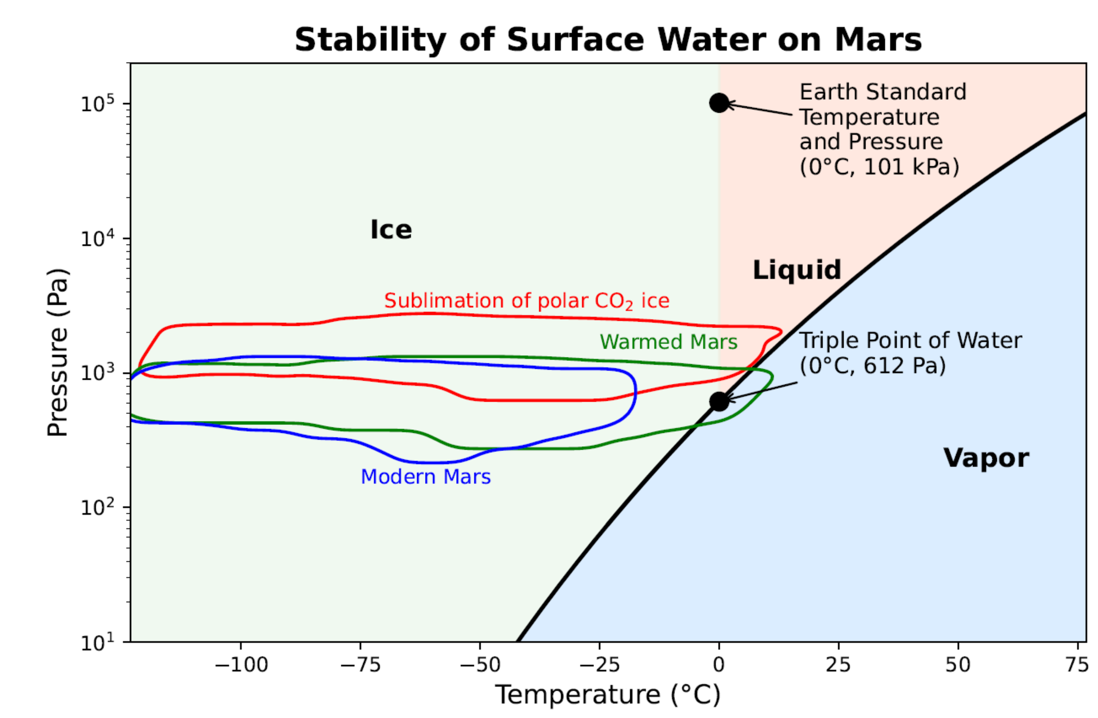

Fig. 5: Phase diagram for H_2O, with the annual distribution of diurnally averaged temperatures in the case of (blue) modern Mars, (green) Mars following 5 years of global warming and (red) Mars following global warming and the thickening of the atmosphere following sublimation of the polar CO_2 ice caps [1].

Fig. 6. A research roadmap for assessing the feasibility of warming Mars. Shared milestones, phase boundaries, and decision points marked. H = Decision made for a human base on Mars [1]

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References. [1] A Science Strategy for the Human Exploration of Mars, 2025, National Academy. [2] Kite E.S. et al., 2026, arxiv.org. [3] DeBenedictis, E.A. et al., *2025,* Nat. Astron. [4] Wordsworth R. et al., 2025, Astrobiology [5] Wordsworth R. et al., 2019 Nat. Astron. [6] Handmer, C., 2024, 10th Intl. Conf. on Mars. [7] Ansari S. et al, 2024, Sci. Adv. [8] Richardson M.I. et al., 2026, GRL. [9] Wordsworth, R. & Cockell, C., 2024, Astrobiology. [10] Wordsworth R. et al., 2025, Astrobiology. [11] McKay, C. et al., 1985. References [3]–[11] support the methods summarized in Table 1 and Fig. 6; see [1] for full discussion.

Green Mars Community Website