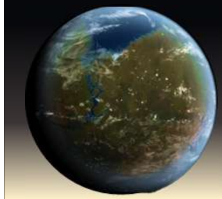

In-situ Resource Utilization for Mars Terraforming Nano Particle Material

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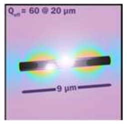
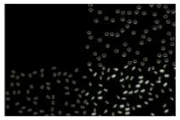
1. University of Colorado 2. MIT Haystack Observatory 3. Astera Institute 4. University of Chicago

Introduction

Terraforming Mars has long been proposed as a pathway toward creating a more habitable environment for future human exploration. One proposed first step is atmospheric warming, which could raise surface temperatures enough to permit seasonal liquid water stability. Recent studies suggest that engineered aerosols dispersed into the Martian atmosphere could provide significant warming by trapping outgoing infrared radiation while remaining transparent to incoming solar radiation [1-4].



A nanorod particle



Real image of the particle

Proposed materials include metallic and carbon-based nanoparticles such as Al, Fe, Mg, and graphene-like carbon aerosols. These particles could produce more than 30 K of global warming. [5]

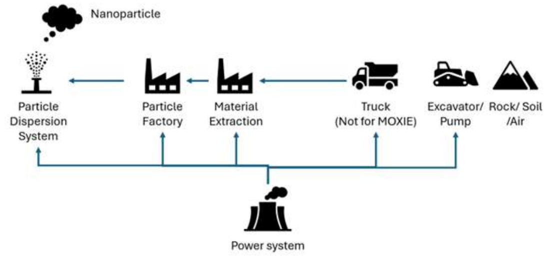
However, sustaining this warming would require deployment of aerosol material at the million-ton scale, while the atmospheric lifetime of the particles is expected to be limited to approximately one year due to atmospheric circulation and deposition processes, necessitating continuous large-scale aerosol production. Transporting such quantities from Earth is impractical, motivating the need for In-Situ Resource Utilization (ISRU) on Mars. This study investigates multiple ISRU architectures capable of producing aerosol feedstock directly from Martian resources, evaluating several extraction and processing pathways using Martian soil, sulfate-rich rocks, water ice, and atmospheric CO_2.

Requirements

Material	Required volume per second (L/sec)	Required mass rate (kg/sec)
Al	60 [5]	162
Mg	60 (Assumed the same as Al)	104
Fe	60 (Assumed the same as Al)	472
Mixed Metals	60 (Assumed the same as Al)	Depends on the composition
Graphene	30 [5]	68 (30L/sec)
MgSO4	1200 (x20 of metals)	3820

The production system must generate aerosol material at million-ton scale using Martian resources while minimizing imported consumables.

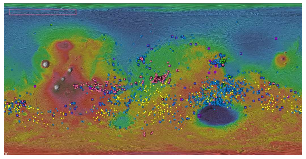
Proposed ISRU Architecture



The overall CONOPS begins with the acquisition of Martian resources including regolith, sulfate-rich rocks, subsurface ice, and atmosphere. Depending on the selected architecture, excavators and processing systems collect and transport raw materials to extraction facilities where metallic elements or carbon feedstock are produced. These materials are then converted into engineered nanoparticles suitable for atmospheric warming. Finally, the particles are dispersed into the Martian atmosphere.

Architecture	Source (Supplement)	Target Material
Molten Regolith Electrolysis (MRE)	Soil	Al, Mg, Fe, Mixed metal
CO_2-electrolysis plus Boudouard reactor	Atmosphere	C
Salty rock water leach	Salty Rock (Atmosphere, Water)	$MgSO_4$, Mg
Acid leach	Soil (Salty Rock, Atmosphere, Water)	Al, Mg, Fe, Mixed metal

The MRE approach extracts metallic elements such as Al, Mg, and Fe directly from Martian soil using high-temperature electrolysis. Water-leaching architectures use sulfate-rich rocks and subsurface ice to produce Mg or $MgSO_4$ particles through dissolution and thermal processing. Acid-leaching systems use sulfuric acid to separate and recover metallic oxides from regolith.



Salty rich locations in Pink [8]

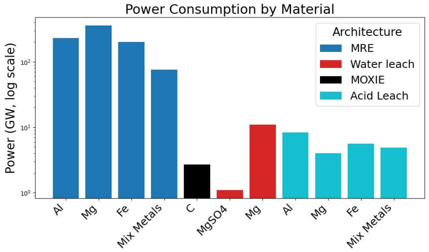
A MOXIE-based architecture was also investigated for carbon nanoparticle production. In this approach, atmospheric CO_2 is processed using a scaled-up MOXIE system to generate carbon monoxide and oxygen. [7] The carbon monoxide is then converted into solid carbon through the Boudouard reaction. Compared to excavation-based methods, the MOXIE pathway eliminates mining operations, reduces system mass, and operates using globally atmospheric resources.

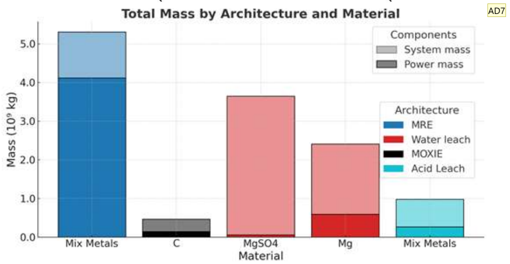
The major driver of the required total payload mass are the power system mass and the feedstock production system mass. We run simulation and defined the required mass to execute and meet the requirement to warm up Mars. Note dispersion system and particle factory system is out of scope for this study.

Results

MRE required the highest power but benefited from operational simplicity and the ability to simultaneously produce Al, Mg, Fe, and oxygen from globally available Martian soil. Water-leaching architectures reduced power demand relative to MRE but required large amounts of water and operation near sulfate-rich deposits, increasing logistical complexity. Acid-leaching methods achieved comparatively low power requirements but introduced significant system complexity and corrosion-related challenges.

Among all evaluated concepts, the MOXIE-based carbon production architecture had the best overall performance. By directly utilizing atmospheric CO_2, the system avoids excavation and transportation operations while maintaining relatively low power demand and system mass. The use of globally available atmospheric resources also minimizes geographic constraints and simplifies mission operations.





Overall, the study suggests that large-scale aerosol production on Mars may be technically feasible using in-situ resources, although substantial improvements in technology readiness and system efficiency are still required. Future work should focus on improving extraction efficiency, extending system lifetime, refining nanoparticle material requirements, and validating long-duration operation under realistic Martian conditions.

REFERENCES

[1] Wordsworth R. et al. (2019) Nat. Astronomy, 3. [2] Handmer C. (2024) 10th Mars, #3025. [3] Wordsworth et al. (2025) Astrobiology 5. [4] Ansaris. et al. (2024) Sci. Adv., 10. [5] Richardson et al. GRL (2026) [6] DeBenedictis E. et al. (2025) Nat. Astronomy, [7] Hecht. et al (2021) [8] Christensen et al. (2009)

Mars terraforming org

Slide 1

AD1 Hecht
Adrian Dumitrescu, 2026-05-29T16:13:39.951

AD2 Very close to the title, needs some spacing.
Adrian Dumitrescu, 2026-05-29T16:14:05.450

AD2 0 Also could make the logos on the right bigger, cant really see them
Adrian Dumitrescu, 2026-05-29T16:14:35.949

AD3 I'd make the writing bigger in the table and make the left hand side column wider since it has most of the writing.
Adrian Dumitrescu, 2026-05-29T16:16:00.168

AD4 I'd summarize this in a single paragraph and make the figure bigger. People want photos.
Adrian Dumitrescu, 2026-05-29T16:16:42.468

AD5 Already listed in the table, no need to do it again.
Adrian Dumitrescu, 2026-05-29T16:17:09.655

AD6 A or the major driver
Adrian Dumitrescu, 2026-05-29T16:17:25.188

AD7 Make this figure as large as it can be. It's the most important element in the poster.
Adrian Dumitrescu, 2026-05-29T16:18:07.798

AD8 Affiliations?
Adrian Dumitrescu, 2026-05-29T16:18:35.585