Johnathan Sattaur

Writing for the Sciences

Prof. Carrie LeBigre

Can We Make Mars Habitable?

1. Introduction

Mars has long been a focal point of scientific curiosity and human imagination as a potential second home for humanity. You've most likely seen it in every form of science fiction: Humanity's first step on the new frontier, being full of untapped mysteries and being the next step in progress for Humanity. It being the next planet in the planetary alignment for our solar system, it almost seems like a no brainer to go there. The red planet, full of rocks and sand dunes; not too far off from Earth in composition. However, in real life, Mars is not how they make it seem.

In reality, Mars is extremely hostile. The planet is missing many key components to house life, more specifically, Human life. But, can we MAKE Mars habitable for human life? Can we change the foundation of Mars in the order of progress? For starters, Mars is, in actuality, mostly extremely cold. It can be very warm during Mars' summer days around the equator, reaching up to 20℃ (70℉). However during winter around poles it can reach down to -153℃ (-225℉). On average it has a temperature of -60℃ (-80℉).

---

2. Background: Defining Habitability and Terraforming, and the Long List of Complications with Mars

2.1 Habitability vs. Terraforming

- **Habitability** in this context refers to the ability of Mars to support stable liquid water and a climate capable of sustaining terrestrial life forms without continuous, large-scale life-support systems.
- **Terraforming** traditionally implies global environmental transformation: thickening the atmosphere, warming the planet, and establishing a stable, Earth-like, self-regulating biosphere.

This review mostly focuses on terraforming as planetary-scale engineering, since “making Mars habitable” ultimately derives from global goals rather than localized shelters or habitats.

2.2 The Atmosphere Problem

For starters, Mars is, in actuality, mostly extremely cold. It can be very warm during Mars’ summer days around the equator, reaching up to 20℃ (70℉). However during winter around poles it can reach down to -153℃ (-225℉). On average it has a temperature of -60℃ (-80℉). This is because of the extremely thin atmosphere Mars has (0.6% of Earth’s atmospheric pressure). The thin atmosphere makes it extremely hard to trap heat inside the atmosphere and other elements necessary for life.

Mars’s atmosphere is predominantly CO_2. Achieving Earth-like surface pressure (≈1 bar) and temperature requires vastly more atmospheric mass than currently present. A central constraint arises from the availability of greenhouse gases and volatiles:

- A landmark study by Jakosky & Edwards (2018) determined that Mars **does not retain enough accessible CO_2** in known reservoirs to raise atmospheric pressure to levels necessary for stable liquid water or to trap significant heat. Their inventory—using data from NASA missions like MAVEN, Mars Reconnaissance Orbiter, and Mars Odyssey—shows that mobilizing all accessible volatiles (atmospheric, ice caps, adsorbed soil CO_2) would only roughly *double* present atmospheric pressure, far short of what would be needed for human habitability. Most CO_2 in mineral deposits or deep subsurface clathrates is inaccessible with current technologies. (ScienceDaily)
- Even if all surface ice and soil volatiles were released, total pressure would remain **orders of magnitude below Earth’s**. Vast amounts of carbon locked in deep crustal minerals remain speculative and would require extraordinary energy and technology to extract. (ScienceDaily)

Mars receives less solar energy due to its greater distance from the Sun, meaning lower equilibrium temperature. Greenhouse warming would have to be much stronger to raise global average temperatures substantially. With low atmospheric pressure and limited greenhouse gas inventory, warming Mars sustainably is challenging.

Mars lacks a strong intrinsic magnetic field, which in turn causes major Solar wind and radiation to continually erode the atmosphere. Any artificially thickened atmosphere would be subject to loss over geological timescales unless mechanisms to reduce escape—such as an artificial magnetic shield—are implemented. The Solar radiation affecting the surface of Mars would make it almost impossible to house life there, whether it be Human or Martian.

2.3 Early Discoveries and Theories

In the 19th century to early 20th century, many theories and discoveries about mars were made. In the early 18th century, Mars was theorized by William Whewell in the mid-19th century to have oceans, seas, and land masses, similar to earth. In the late-19th century, Italian astronomer Giovanni Schiaparelli discovered linear features on Mars, naming them “canali” or channels. It had already been discovered in the 17th century that Mars had polar ice caps. This was the basis for all of our future discoveries and theories about Mars. From seeing the polar caps, channels, lakebeds, and sediment, scientists believed that there could’ve been flowing water on Mars. Researchers have recently discovered that through the historic study of the magnetic field, they were able to ascertain that the Mars dynamo– the global magnetic field created by convection in the planet’s core– was around longer than previously assumed. Using the magnetic populations in rocks on Mars, you could determine when the magnetic poles flipped, showing fossilized minerals surrounding certain pockets.

---

3. Methodology of Research

Most sources simply use observational methods, such as reviewing images and telescope imagery. However sources like the Harvard Gazette use observational methods on physical Martian rocks that we have. The study by Dicaire, et al, uses a hypothesis and test study where they used simulation environments to determine concentration of greenhouse gases in an engineering vs. non-engineered climate. The main downfall to the observational methods of research are simply that we can only determine so much based on imagery. The data collected through images will never be the same as the data actually on Mars.

---

4. Engineering Proposals for Making Mars Habitable

4.1 Mobilizing Native Volatiles

Early terraforming proposals focused on mobilizing Mars’s own volatiles:

4.1.1 Sublimation of Polar CO_2 Ice

One idea, dating back to Carl Sagan’s early work, suggested vaporizing polar CO_2 ice to thicken the atmosphere and trap solar heat. (Harvard Gazette) However, recent data shows that the total CO_2 in polar caps and adsorbed in regolith is insufficient to raise pressure significantly. Even hypothetically releasing all such volatiles would only modestly increase atmospheric density. (ScienceDaily)

4.1.2 Soil Heating and Strip Mining

Heating large areas of soil to release CO_2 adsorbed on dust particles or extracting carbon from carbonate minerals has been proposed. But these ideas face serious scalability and energy constraints, requiring operations akin to planetary-scale strip mining—beyond present-day technology. (ScienceDaily)

4.2 Importing Volatiles from External Sources

Where Mars lacks resources, importing them externally has been proposed.

4.2.1 Redirecting Comets or Asteroids

Massive comet or asteroid bodies rich in water, nitrogen, and volatiles could be redirected to impact Mars, delivering greenhouse gases and other elements. While theoretically possible, steering thousands of such bodies safely and precisely is far beyond current capability and would carry grave risks.

4.2.2 Delivery of Nitrogen

Nitrogen is essential for a breathable atmosphere. Mars's indigenous nitrogen is extremely limited, so proposals include transporting nitrogen-rich materials to Mars. These schemes require high-energy launches and enormous investment.

4.3 Artificial Greenhouse Gases and Climate Engineering

With insufficient native CO_2, attention has turned to manufactured greenhouse gases.

4.3.1 Synthetic Super Greenhouse Gases

Studies have considered creating powerful greenhouse gases with much higher heat-trapping potentials per molecule than CO_2. Examples include certain fluorinated compounds that, if introduced, could warm the planet more effectively. (PMC)

However:

- These compounds would need massive production on Mars itself—ISRU (in situ resource utilization) facilities capable of producing greenhouse gases at planetary scales are purely conceptual.

- Some proposals (e.g., iron or aluminum nanoparticle aerosols) aim to create an artificial radiative effect, but their climatic impact, persistence, and unintended consequences remain uncertain.

Climate modeling studies continue to examine these approaches, but none currently point to a near-term feasible path.

4.4 Localized Environmental Engineering ("Para-Terraforming")

Given the difficulty of whole-planet manipulation, recent research explores **localized methods**.

4.4.1 Solid-State Greenhouse Using Transparent Covers

A 2019 study suggested that placing silica aerogel covers over localized regions could create warm microenvironments. Silica aerogel transmits visible light while reducing infrared emission and blocking harmful UV radiation. Under such covers, temperatures could rise above water's freezing point, enabling photosynthesis and liquid water in those controlled zones.

This "para-terraforming" or *regional habitability* differs from global terraforming. It could enable human habitats and photosynthetic life in limited areas without altering the whole planet.

4.5 Creating an Artificial Magnetosphere

One of the most extreme engineering proposals is to reduce atmospheric loss by installing large magnetic systems:

- Concepts include placing an artificial magnetic shield at the Mars–Sun L1 point or constructing massive electromagnets around the planet to deflect solar wind and reduce atmospheric erosion.

These ideas are ultimately speculative, requiring energy and materials far beyond current engineering capacity. But they represent important thinking about how to *retain* introduced or generated atmospheres over long times.

---

5. Life Support Technologies vs. Planetary Engineering

While global terraforming remains far future or speculative, enabling **sustained human presence** may not require full planet habitability:

5.1 In-Situ Resource Utilization (ISRU)

ISRU aims to live off the Martian environment—producing water, oxygen, building materials, and fuel locally rather than shipping everything from Earth.

- **Oxygen Production:** NASA's MOXIE experiment on the Perseverance rover demonstrated oxygen production from Martian CO_2. While small scale, it proves core technology for local life support. Scaling ISRU is crucial for sustainable human bases.
- ISRU also includes extracting water ice, converting local materials for construction, and producing propellants.

Such technologies support the idea of **human habitats** without requiring global habitability.

---

6. Biological Approaches

Biology has been proposed as a terraforming agent—using microbes or engineered organisms to modify Martian soil and atmosphere.

- Concepts include engineered extremophiles that could survive harsh Martian conditions and gradually produce greenhouse gases or oxygen, or biomineralization for construction.
- Synthetic biology research explores future possibilities for life-based environmental engineering, but ethical, ecological, and planetary protection concerns are significant.

---

7. Ethical, Legal, and Planetary Protection Issues

Terraforming Mars raises critical ethical questions: Altering Mars' could destroy any indigenous life or other biosignatures yet to be discovered. There are also many debates in which whether humanity has the right and governance to change and transform another planet— a pristine scientific environment still. As of right now, any exploration to other celestial bodies is done for the sole purpose of progress, under the Outer Space Treaty, which just details that humanity is not allowed to use space for military use and national appropriation of space. Military bases are not allowed along with weapons of mass destruction to be on or near other celestial bodies. Space absolutely **CANNOT** be claimed. This also limits the contamination of other planets. Any astronaut or nation is responsible for contamination on other planets. This treaty would be the main blockage to terraforming Mars because it simply doesn't allow humanity to do so. As long as everyone agrees, it could be overridden and pushed on to progress for humanity. These philosophical and policy dimensions are increasingly present in the literature, urging careful deliberation before any broad environmental modification.

---

8. Synthesis: Feasibility, Timescales, and the Path Forward

8.1 Feasibility

Based on current scientific knowledge:

- **Global Galileo-style terraforming** of Mars into a thick, warm, Earth-like world with a self-sustaining biosphere is **not feasible with present-day technology** and known native resources. This conclusion rests largely on the CO_2 inventory limitation determined by Jakosky & Edwards (2018).
- **Localized habitability** (para-terraforming) using engineered materials or structures is more attainable in the near future (decades to centuries), particularly for establishing sheltered bases or controlled ecosystems.

8.2 Timescales

- **Near term (10–50 years):** Continued ISRU development, habitat construction, small-scale oxygen production, and robotic exploration.
- **Mid term (50–200 years):** More advanced climate engineering experiments (e.g., greenhouse gases at larger scales), regional environmental projects, robust in-situ manufacturing.
- **Long term (200+ years):** Potential breakthroughs in planetary engineering—massive atmospheric modification, magnetic shielding, or substantive biological terraforming..

---

9. Reflections

What does taking an interdisciplinary approach to this topic offer to research? The different research styles and disciplines from each source highlight the broad spectrum of issues and problems that face this topic. Not only is it an engineering problem, but a biological problem, a chemistry issue, and a political issue as well. However it narrows down the simple answer that we just aren't ready. The biologists highlight how unsustainable it is for life on Mars as well as the elements for life it's missing. The chemistry approach offers insight into the issues with the ozone layer and the missing elements in the atmosphere to house life and protect the planet from Solar radiation. The engineers simply tell us that we are not technologically advanced to transform Mars' atmosphere and magnetic shield. The main points from them all tell us we can't just make Mars into the "next step" on the infinite frontier that is space.

Though, the many disciplines creates a new understanding of the issue. There are so many elements on the mission to Mars and so many hurdles to go through. It gives us a roadmap to how we can make Mars into a livable planet and what information we are still missing on the Martian environment.

---

10. Conclusions

The scientific literature converges on a single, central conclusion: **we CANNOT make Mars fully habitable in a global, Earth-like sense using present technologies or Mars's existing resources alone.** Major engineering challenges—limited accessible greenhouse gases, atmospheric loss, energy requirements, and ethical considerations—place full terraforming far into the future.

However, **near-term efforts** focused on human habitats, local climate control, and ISRU can build a stepping stone toward longer-term goals. Advances in climate models, material science (e.g., aerogel covers), and space infrastructure may one day bring more ambitious plans within reach.

While Mars's transformation into a second Earth remains a distant and uncertain possibility, the pursuit of knowledge along that path continues to deepen human understanding of planetary science, ecology, engineering, and ethics. For now, the only true plan for humanity to live on Mars would be to create habitats under the surface. However, such a lifestyle could never fit humanity

---

References (Selected)

- Burrows, Leah, and Leah Burrows. "A Way to Make Mars Habitable." *Harvard Gazette*, 9 Nov. 2023, news.harvard.edu/gazette/story/2019/07/making-mars-habitable.
- Dicaire, I., et al. "Using Martian Climate Models to Assess the Potential of Artificial Greenhouse Gases to Increase Martian Surface Temperatures." *64nd International Astronautical Congress*, conference-proceeding, 2013, www.esa.int/gsp/ACT/doc/ESS/ACT-RPR-ESS-2013-IAC-MarsClimateEngineering.pdf.

- Gerstell, M. F., et al. “Keeping Mars Warm With New Super Greenhouse Gases.” *Proceedings of the National Academy of Sciences*, vol. 98, no. 5, Feb. 2001, pp. 2154–57, doi:10.1073/pnas.051511598.
- Manning, Anne J., and Anne J. Manning. “Mars May Have Been Habitable Much More Recently Than Thought.” *Harvard Gazette*, 1 Nov. 2024, news.harvard.edu/gazette/story/2024/10/mars-may-have-been-habitable-much-more-recently-than-thought.
- “Mars Terraforming Not Possible Using Present-day Technology.” *ScienceDaily*, 18 July 2018, www.sciencedaily.com/releases/2018/07/180730120307.htm.
- The Mars Society of Canada. “The Habitability of Mars.” *The Mars Society of Canada*, 20 Oct. 2024, www.marssociety.ca/the-habitability-of-mars.
- Wasteigerwald, and Wasteigerwald. “NASA: New Insights Into How Mars Became Uninhabitable - NASA Science.” *NASA Science*, 8 Oct. 2024, science.nasa.gov/solar-system/planets/mars/nasa-new-insights-into-how-mars-became-uninhabitable
- Zhong, Yubin, et al. “Advancements in Mars Habitation Technologies and Terrestrial Simulation Projects: A Comprehensive Review.” *Aerospace*, vol. 12, no. 6, June 2025, p. 510, doi:10.3390/aerospace12060510.