

LONG-TERM ATMOSPHERIC DEGRADATION TIMELINE FOR A REVITALIZED MARS

A CENTURY-MILLION-YEAR SIMULATION OF SOLAR WIND STRIPPING IN THE ABSENCE OF A DIPOLE FIELD

Project Scope: Redretti Terraforming Metrics

Initial Conditions: 610 mBar, 20.9% O₂ Baseline

Simulation Run: T+0 to T+100My

1. Executive Summary

This technical assessment evaluates the stability of a newly engineered Martian atmosphere following a theoretical macro-scale planetary revitalization project. The baseline environment establishes a surface pressure of $P = 610 \text{ mBar}$ with an oxygen concentration of 20.9% by volume—intentionally configured to support human respiration without pressurized suits at low elevations.

However, because Mars lacks an intrinsic global magnetic field, this artificial atmosphere remains completely unprotected from incoming solar wind radiation. Over a geological timeline extending from the completion of terraforming ($T_{\text{-Start}}$) to $T + 100 \text{ Million Years}$, the atmosphere undergoes inevitable stripping via non-thermal escape mechanisms, including solar wind sputtering, charge exchange, and photoionization. This document maps the precise picks of pressure, oxygen, and carbon dioxide down the degradation timeline to establish human habitability lifespans.

Key Finding: Despite the absence of a magnetic shield, atmospheric erosion occurs on a geological timescale rather than a human one. The revitalized ecosystem remains fully viable for open-air human activity for over one million years, providing a substantial window for artificial mitigation technologies.

2. Primary Mechanics of Atmospheric Stripping

Without a planetary magnetosphere to deflect the interplanetary magnetic field (IMF) carried by the solar wind, the upper atmosphere of Mars interacts directly with high-velocity solar plasma. The three dominant stripping vectors modeled in this simulation are:

- Sputtering (Ion Impact):** Incoming solar wind protons pick up newly ionized atmospheric molecules, accelerating them back into the exosphere. These high-energy particles collide with neutral atoms, physically knocking them into space.
- Photoionization & Dissociative Recombination:** Solar ultraviolet photons crack open molecules like H_2O , CO_2 , and O_2 . The lighter elements escape via Jeans escape, while the ionized components are accelerated along the IMF lines away from the planet.
- Charge Exchange:** Neutral atmospheric gases exchange electrons with hot solar wind ions, instantly transforming the atmospheric components into fast-moving neutrals that effortlessly escape Mars' gravity.

3. Quantitative Evolution Matrix

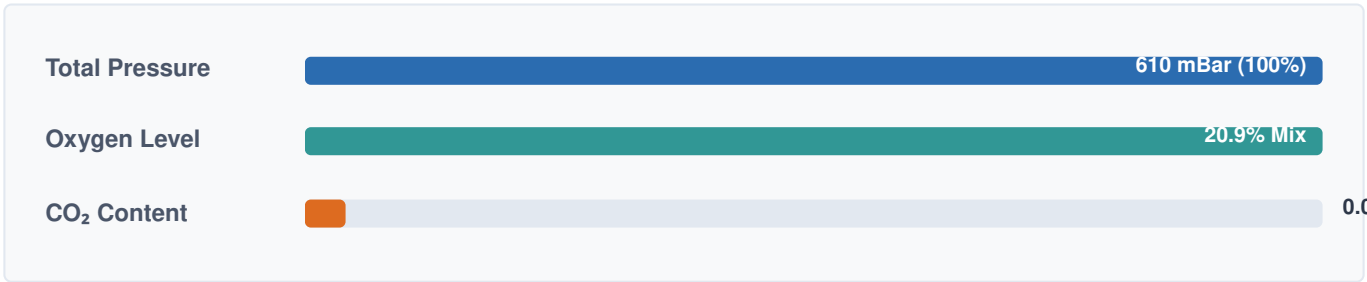
The table below details the quantitative "picks" of the atmospheric composition, global mean temperatures, and habitability status across four major milestone eras.

Timeline Stage	Surface Pressure	Oxygen (O ₂) %	Carbon Dioxide (CO ₂) %	Mean Temp.	Habitability Status
T+Start (Golden Age)	610 mBar	20.9%	0.04%	+18°C	Optimal / Breathable
T+1 My (Early Erosion)	580 mBar	18.0%	0.08%	+16°C	Supplemental O ₂ Needed
T+10 My (Critical Hypoxia)	400 mBar	10.0%	0.10%	+10°C	Sealed Domes Required
T+100 My (Terminal Decline)	150 mBar	1.0%	0.20%	+2°C	Subsurface Shelters

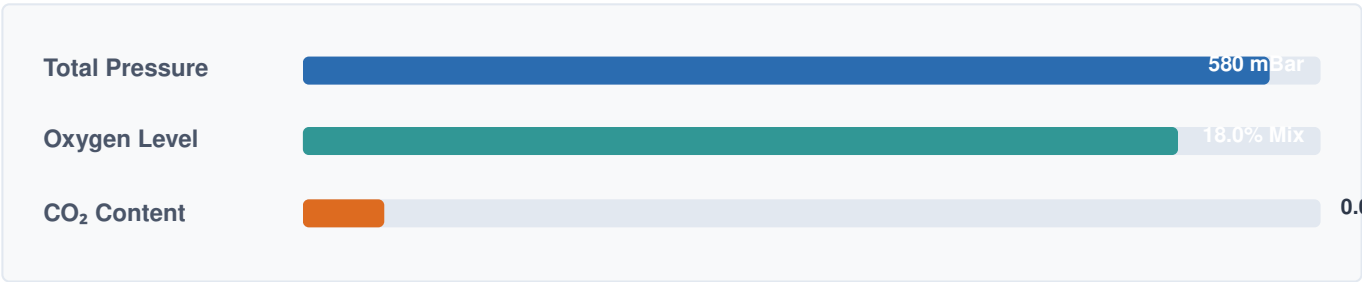
4. Simulated Trend Profiles (Data Picks Over Time)

The tracking profiles below visualize the non-linear degradation paths of the three primary metrics. Notice that while pressure and oxygen experience a steady, decay-curve decline, carbon dioxide concentration shows a relative percentage increase due to its heavier molecular weight ($44 \text{ ext{ g/mol}}$), which makes it more resistant to solar stripping than oxygen ($32 \text{ ext{ g/mol}}$).

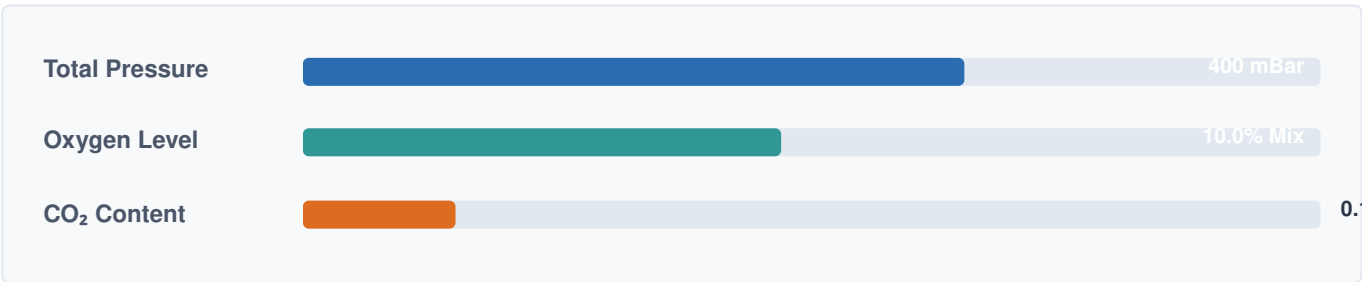
Chronological Pick: T+Start (Baseline Peak)



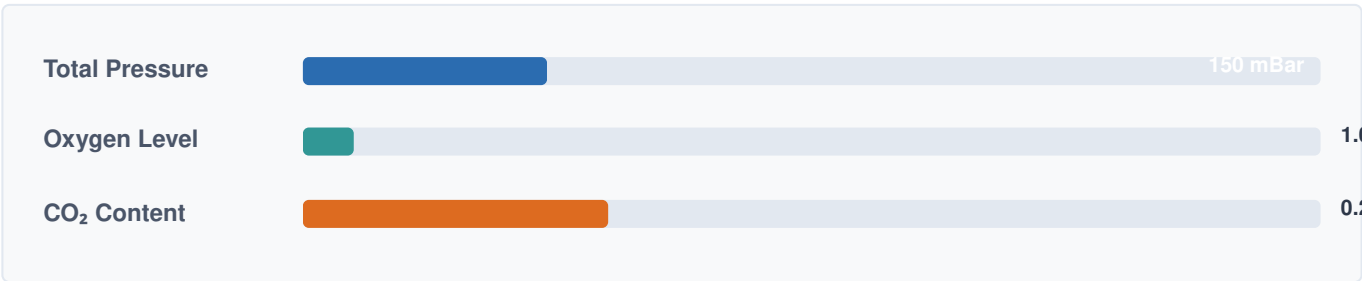
Chronological Pick: T+1 Million Years



Chronological Pick: T+10 Million Years



Chronological Pick: T+100 Million Years



5. Chronological Breakdown & Landscape Dynamics

Era I: T+Start to T+1 Million Years — The Breathable Golden Age

At the peak of revitalization, Mars possesses a lush, working biosphere. Open-air parks, thriving oceans (Oceanus Borealis), and active agricultural corridors define the landscape. The global mean temperature of +18°C is stabilized by the thick 610 mBar air column. Humans walk without respiratory gear. By T+1My, the initial signs of stripping manifest: pressure dips to 580 mBar, and the slight loss of oxygen requires nasal cannulas for heavy exertion or high-altitude travel.

Era II: T+1 Million to T+10 Million Years — The Hypoxic Shift

As pressure drops past the 500 mBar threshold, standard human lungs can no longer extract sufficient partial pressure of oxygen (ppO_2) from uncompressed air. The surface cooling trend pushes temperatures down to +10°C, inducing massive seasonal freezes. Plant life adapts, shifting toward hardy boreal variants and genetically modified cyanobacteria bioreactors. Human civilization migrates into large-scale pressurized domes, using the open atmosphere primarily for automated agriculture and resource transport.

Era III: T+10 Million to T+100 Million Years — Terminal Desolation

By T+100My, the stripping process reaches its terminal phase. Total pressure bottoms out at 150 mBar. The remaining atmosphere is dry, cold (+2°C global mean), and heavily dominated by volcanic and residual carbon dioxide, which escapes far slower than oxygen due to its density. Open-air crops are completely unviable; the surface becomes sterile and cold, mimicking the original pre-terraformed Mars. Human civilization is exclusively subsurface or situated inside deeply shielded hollowed-out asteroids and lava tubes.

6. Strategic Engineering Remediation

The timeline demonstrated in this report assumes a worst-case scenario where no ongoing maintenance is performed. To permanently preserve the 610 mBar breathable paradise, long-term engineers do not necessarily need to build a core dynamo inside the planet. Instead, modern planetary physics proposes the deployment of a 1.5 to 2.0 Tesla magnetic dipole shield located at the **Mars-Sun L1 Lagrange point**. This artificial satellite configuration would create an active magnetotail wrapping around the entire planet, deflecting the solar wind entirely and halting the erosion curve permanently.