# The Terraformation of Worlds

*"It is impossible to accede to a fundamentally new environment without experiencing the inner terrors of a metamorphosis." - Pierre Teilhard de Chardin*

## I. Introduction – *Man and Mars*

Among the worlds beyond Earth potentially accessible to man in the foreseeable future, only the planet Mars falls within the known parameters of life. Given the present and potential range of human technological capabilities, in the relatively near future it may be possible to profoundly modify environmental and ecological conditions on Mars by a process that has come to be known as terraformation. The goal of terraformation is to render Mars more like Earth.

The technological requirements for the Martian terraformation process are reasonably well understood among a small community of planetary scientists and space exploration entrepreneurs. Like Arthur C. Clarke's unpatentable conceptualization of the geosynchronous communication satellite in the 1940's, some of the requisite technologies for planetary engineering are beyond the present technical or economic capabilities of existing institutions and enterprises, but the path forward is visible, and well within the scientific horizon. It is likely that the terraformation of Mars, or its precursor step *ecopoiesis*, will be possible by 2100.

A project management approach is used to illustrate the process of the terraformation of Mars. A simple analysis of the process design illustrates the risks and gauges the complexity of the planetary engineering project.

Since terraformation seems possible, the ethical question about life and survival it poses must be answered, and the philosophical consequences of the answer fully understood.

I believe the answer to be wisely affirmative, justifiably aggressive, with optimistically profound implications for life from Earth, endowed with sentience, empowered to prosper beyond its home.

## II. The Process of Terraformation

### Worlds of the Solar System – *Quo Vadis?*

There are nine known planets, many tens of moons, and countless asteroids and comets, in Earth's solar system. Much of the solar system has been surveyed by machines launched from Earth. The orbits of three rocky planets and one moon, including Earth and Earth's moon, occupy a radial zone generally regarded as the region of the solar system suitable for organic life as it is known on Earth. This habitable zone is defined by its distance from the sun[1] and the range of flux of solar energy received at the respective planetary surfaces. The planetary objects that orbit the sun within the habitable zone are similar in size and composition, but other factors have produced four very different worlds. In order of distance from the sun, they are Venus, Earth and Moon, and Mars. Only one is known for certain to harbor life, and that life has briefly touched only one of the other three. The Earth's moon is a frequently mentioned site for colonization, but conditions there demand that all necessary life support materiel be imported from Earth. Unmanned spacecraft from Earth have extensively examined Venus and Mars, and Mars especially remains a primary object of research, where progressively closer inspection will eventually lead to human exploration. Table 1 compares the three planets of the habitable zone. It can be seen that Venus is most unlikely to host organic life due to surface temperature and atmospheric pressure. Unmanned radar mapping and atmospheric analysis indicates that Venus is a volcanically active runaway greenhouse, a virtually uninhabitable planet not suitable for human visitation or colonization. At the other end of the habitable zone's range is Mars. Much recent evidence points to a warmer wetter Mars in the past. Cold and dry now, it is possible, perhaps even likely, that Mars is, or was, the home of life. The human exploration and colonization of Mars is an active subject of space mission planning in the United States and elsewhere. Beyond the habitable zone and within the orbit of Venus is Mercury, a very hot planet that need not be considered further in our discussion. Beyond the habitable zone and outside the orbit of Mars, lies most of the planetary mass of the solar system. The grand, chemically complex, inhospitable gas giants Jupiter, Saturn, Uranus, and Neptune, are home to several interesting moons. Two moons of the outer planets possess tantalizing yet scientifically indeterminate potential for life: Europa of Jupiter, and Titan of Saturn. Europa appears to have an ocean of liquid water beneath a crust of ice and receives as much energy (gravitational-kinetic and electromagnetic) from Jupiter as from the sun (solar); tidal forces at its core may generate life-sustaining warmth in Europa's depths. Titan has a thick methane atmosphere and perhaps methane seas at a sufficiently low temperature where liquid methane could play the role water does in the habitable zone. Unmanned missions, including a drilling submarine probe for Europa and a parasail- or balloon- supported atmospheric descent probe for Titan, have been proposed, but primarily due to their distance from Earth neither moon will be a candidate for direct human exploration or colonization within the technological horizon of this essay. The ninth planet and its similar companion, Pluto and Charon, have yet to be examined by robots dispatched from Earth.

[1] Solar distance is a parameter predicting the presence of heavier elements such as carbon in the solar system, based on gravitational models of their distribution in the proto-planetary accretion disk.

**Table 1. (Following McKay, "Bringing Life to Mars.")**

**Comparison of the three planets within the habitable zone of Earth's solar system.**

| | **Earth** | **Mars** | **Venus** |
|---|---|---|---|
| **Gravity (G)** | 1 | 0.38 | 0.91 |
| **Length of Day** | 24 hours | 24.61 hours | 117 Earth days |
| **Length of Year (Earth Days)** | 365 | 687 | 225 |
| **Axis Tilt (Degrees)** | 23.5 | 25.2 | 2.6 |
| **Mean Sunlight at Planet ($Wm^2$)** | 345 | 147 | 655 |
| **Mean Surface Temp (C)** | 15 | -60 | 460 |
| **Surface Pressure (A)** | 1 | 0.008 | 95 |
| **Most Abundant Gas in Atmosphere** | $N_2$, $O_2$ | $CO_2$ | $CO_2$ |

Of the many sister worlds in Earth's solar system, then, only Mars presents the prospect for human colonization in anything remotely resembling an Earthlike habitat.

## Terraformation Technologies – *Tools of the Trade*

The first steps toward terraformation of Mars are exploration and colonization. Exploration will supply essential data regarding the current state of Mars, variations in local conditions, and most importantly the presence of $H_2O$, $CO_2$, and other volatiles in the Martian soil and atmosphere, which will establish the initial conditions of the terraformation process. Colonization will establish the *in situ* industrial base for terraformation technology; terraformation, in turn, will assure the colony's long term viability.[2]

The overall process of terraformation consists of two phases. The first phase achieves a state of ecopoiesis,[3] in which an anaerobic biosphere is established; surface temperature

[2] Zubrin [2].
[3] Term coined by R.H. Haynes in 1990, according to Fogg [9].

and atmospheric density are significantly increased. The second phase is complete terraformation, in which an aerobic biosphere inhabitable by humans is established.[4]

The fundamental requirements of exploration and colonization are predicated on a profound manifestation of the human will to conquer the Martian frontier. This level of commitment has not been evident for a very long time in the traditional home of manned space exploration, the United States. Other nations may or may not have the expertise, money, and courage to attempt interplanetary flight.[5] These qualms notwithstanding, most American and British researchers clearly expect (hope is probably a better term) the terraformation of Mars to be practical and possible by 2100.

Five technologies have emerged as primary enablers of terraformation:

- Industrial
- Biological
- Genomic
- Nanomic
- Orbital

Industrial technologies will be based on *in situ* Mars manufacturing capabilities. The massive production of super-greenhouse gases such as either halocarbons or perfluorocarbons has been proposed[6] to initiate an increase in surface temperature and facilitate the intended controlled greenhouse effect. Another proposed application is the production of albedo-reducing material to be spread over the poles, accelerating heat absorption that in turn would promote the release of polar carbon dioxide to initiate greenhouse warming. Virtually the whole range of manufacturing techniques necessary

[4] Termed coined by science fiction writer Jack Williamson in 1942, according to Fogg [9].
[5] The present stagnation was anticipated 50 years ago when Robert A. Heinlein accurately forecast our hiatus in deep space exploration. Heinlein's timeline of future history appeared in the title pages of several of his books published in the early 1960's, such as *The Green Hills of Earth* and *The Man Who Sold the Moon*. It is a matter of deep personal concern as to when men of imagination, strength, and indomitable will may again turn their hearts and minds to the frontier in the sky.
[6] Interestingly, in 1984 by James Lovelock, originator of the *Gaia* hypothesis. Fogg [9].

for planetary engineering exist or are on the drawing board today, and they will be in the toolkit of Martian colonization.

Biological and Genomic technologies are likely to be highly interacting if not integrated by the time of Mars terraformation,[7] so this broad set of bioengineering capabilities will be referred to as Biogenomics. Biogenomics will be the core technology for the terraformation of Mars. The production and wide deployment of GEMO's[8] will be the first order of business on the road to ecopoiesis.

The fact that there has been no known demonstration of its viability makes any nanotechnological solution or proposal with respect to Martian planetary engineering impossible to assess. This technology may be equally dubious one hundred years from now.[9] However, because breakthroughs are possible, Nanomics will be included in our gauge of the planetary engineering challenge below.

Several phases of terraformation are addressed by proposals that entail delivery of very substantial amounts of energy or mass from orbit. Foremost is the deployment of one or more very large space based reflectors (SBR, or soletta) to deliver solar energy to the Martian surface. This energy can be used for direct heating of an area of the Martian surface such as the southern polar cap, or to manipulate surface meteorological conditions, for example, to generate ultraviolet- blocking dust storms in the event of localized ozone layer failure.[10] One design for this type of SBR, similar to a solar sail, describes a mirror of 125-kilometer radius, composed of an aluminized Mylar material at

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[7] My assumption is that the current rate of progress in the fields of genomics, molecular biology, and bioengineering in general will continue, and probably increase, throughout the 21st century. The pace of evolution of this set of technologies in this century will match that of aviation and electronics in the last.
[8] Genetically engineered Martian organism. Hiscox and Thomas [4], and Hiscox [10].
[9] Is nanotechnology more dubious than terraformation? To my knowledge, in the field of nanotechnology (I do not include micro-engineering results in electronics) we have seen nothing but Drexler's book, many speculative treatises, and some interesting *Star Trek* episodes. With regard to terraformation and planetary engineering, we have the whole history of manned and unmanned space exploration, the burgeoning ecological sciences, the explosive growth of biological technologies, and a planet filled with industrial and large-scale engineering capabilities.
[10] Hiscox and Linder [8].

a density of 4 tons/km$^2$, with a total mass of 200,000 tons.[11] These delivery systems may be far more practical by the time of Mars terraformation than they are today and may very well be part and parcel of standard operating procedure for an interplanetary culture.

## Planetary Engineering of Mars – *Project Management View*

The terraformation technologies discussed above will be combined, integrated, and deployed by the planetary engineering project implemented to render Mars more like Earth. The steps required are known in broad outline, well enough to lay out a project plan for terraformation. The planetary engineering plan can then be assessed for difficulty and the areas of highest risk can be identified.

As shown in Chart 1, the high-level planetary engineering plan for Mars terraformation consists of the following steps.

Temperature and Pressure stage – Super-greenhouse gases, halocarbons or perfluorocarbons, are used to initiate a greenhouse effect which will cause an increase in surface temperature and atmospheric pressure, thus stimulating the process of $CO_2$ liberation.

$CO_2$ stage – A $CO_2$ positive feedback model is implemented.[12] As the temperature begins to rise, $CO_2$ is released from (a) the ice of the polar caps, thus contributing to an increased greenhouse effect. As the temperature and pressure continue to rise, $CO_2$ is released from (b) the Mars regolith, the soil of higher latitudes. Here there is a major risk. The value of the parameter Zubrin calls $T_d$ is unknown, and will remain so until Martian colonists can experiment under local conditions. The $T_d$ parameter determines how much energy is required to release $CO_2$ from the regolith, and its value has a major impact on the economics and power requirements of the planetary engineering project.

[11] Zubrin and McKay [7], pp. 318.
[12] Zubrin and McKay [7] and Zubrin, *The Case for Mars*, Chapter 9.

Huge (hundreds of square kilometers of extremely thin highly reflective material) space based reflectors may be deployed to apply very large amounts of energy to the polar caps or specific $CO_2$-abundant areas at higher latitudes

Solar Radiation stage – Solar insolation at the orbit of Mars is sufficient for photosynthesis. However, on Mars there is no atmospheric protection from lethal ultraviolet radiation. Ozone production during the greenhouse era is promoted by low water vapor abundance in the Martian atmosphere at most latitudes.[13] Figure 1 illustrates the analysis of Hiscox and Linder[14] of the Martian ozone cycle during $CO_2$ stage (b), where CO = carbon monoxide, $CO_2$ = carbon dioxide, $H_2O$ = water, O = atomic oxygen, $O_2$ = molecular oxygen, $O_3$ = ozone, and M = pressure. In this analysis, the photodissociation of carbon dioxide creates atomic oxygen, which combines with molecular oxygen to form ozone. Ozone in turn is destroyed by photodissociation and also in an interaction with water vapor released from the regolith. More carbon dioxide is released from the regolith leading to the formation of new ozone and the cycle continues. Until and unless this process takes hold harsh UV conditions will still prevail at the Martian surface. GEMO's introduced to create the ecopoiesis phase may incorporate an endolithic strategy (they will hide under rocks), they may cultivate a pigmentation strategy, or even a matting behavior, where an exposed outer layer of dead GEMO's protects the living interior layer.[15]

[13] Hiscox and Linder [8].
[14] Hiscox and Linder [8].
[15] Hiscox [10] and Hiscox and Thomas [4].

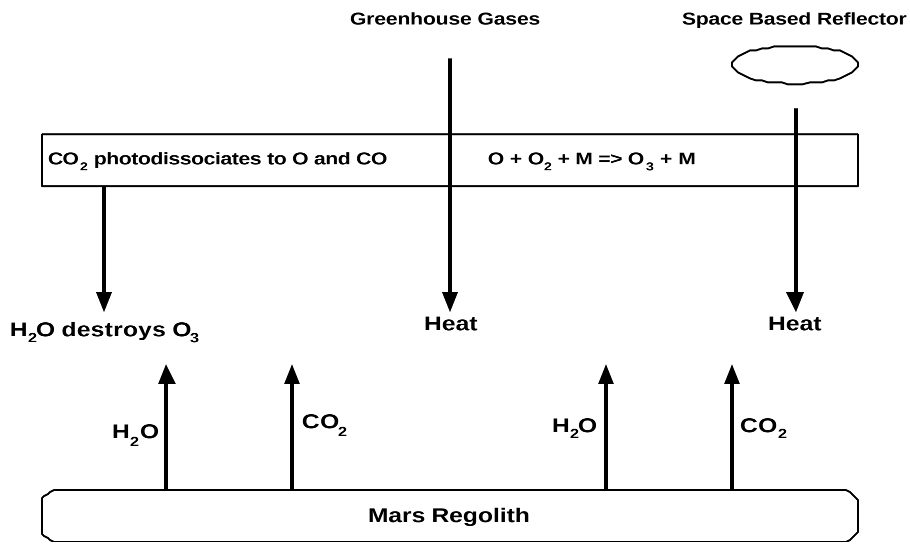



**Figure 1.Greenhouse Effect and Ozone Production on Mars (based on Hiscox and Linder [8]).**

Ecopoiesis stage – An anaerobic biosphere. The application of biogenomics to introduce anaerobic life in the form of the GEMO.[16] The GEMO's themselves will be challenged to survive the dynamically stressed conditions of the Martian environment. At this point, a major assessment of the planetary engineering project ought to be conducted to assure that the assumptions of the terraformation model still hold and the commitment to proceed is still firm, for the next phase of the planetary engineering project could take a very long time.

$O_2$-$N_2$ stage – Water frozen in permafrost will be released. Current speculation is that some nitrogen locked in soil nitrates will be conferred to the atmosphere, but quantity of nitrates available in the Martian soil remains to be discovered by human or robot prospectors. To address this deficiency, Biogenomic solutions for GEMO's to metabolize nitrates to create a nitrogen atmospheric buffer gas and rapidly photosynthesize oxygen have been proposed.[17] Ultimately, breathable air and water vapor will begin to displace the originally planetary-engineered greenhouse gases. Some researchers conjecture a Nanonic acceleration of this part of the terraformation process,

[16] Hiscox and Thomas [4].

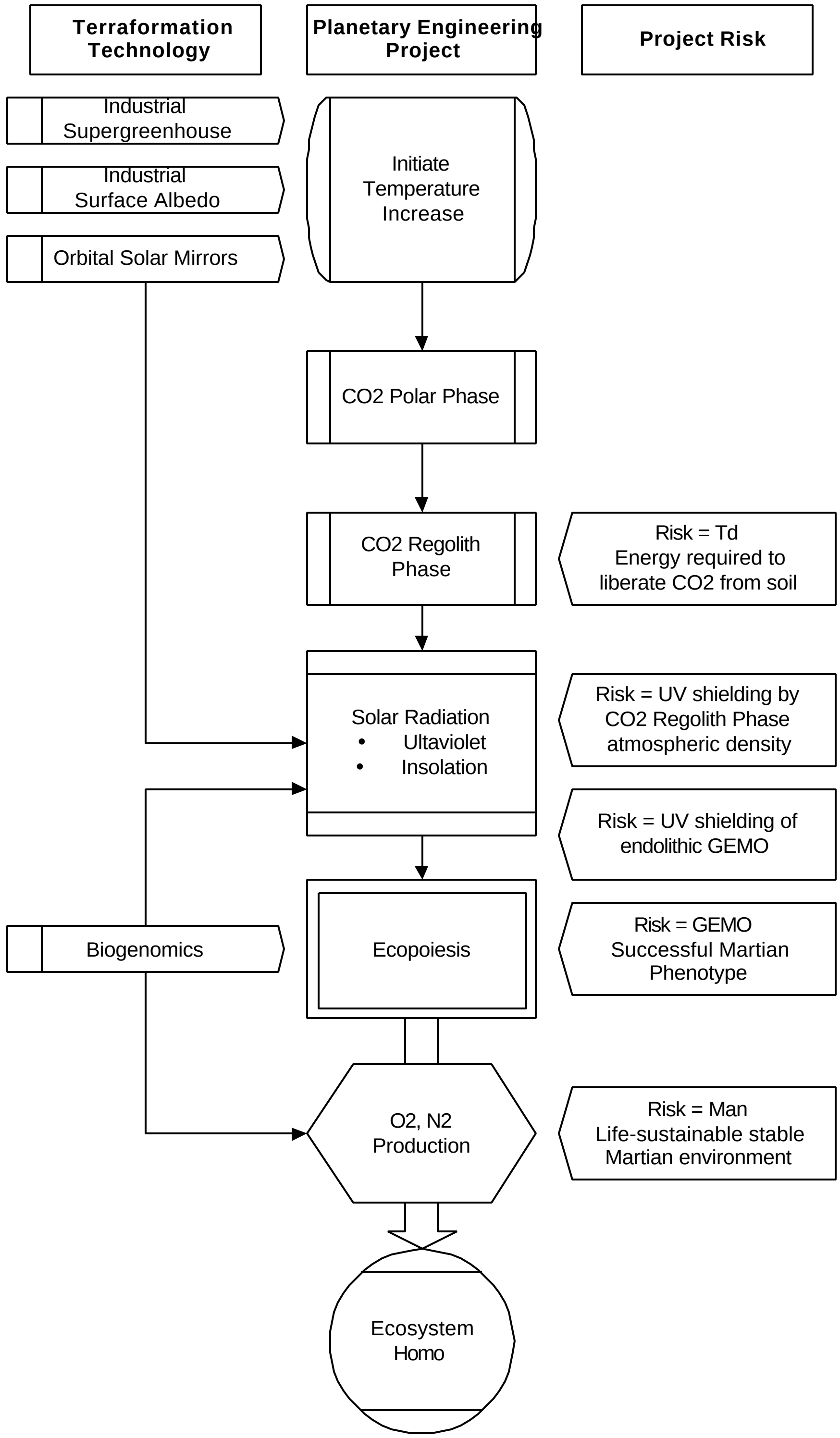
which could otherwise take anywhere from a few decades to millennia. By this stage the risk to any persistent indigenous Martian life has reached its most profoundly lethal threat.[18]

Ecosystem Homo stage[19] – Terraformation is complete. A sustainable aerobic biosphere – in the sense that the terraformation technology to maintain it is in place – has been created on Mars. The surface is open to relatively unprotected human habitation.

[17] Hiscox and Thomas [4].
[18] Hiscox [10].
[19] My term.

## Chart 1.

## Planetary Engineering of Mars – Project Management View[20]




[20] My assessment of the tasks, technologies, and risks.

Table 2 summarizes my appraisal of which terraformation technology purports to address each planetary engineering challenge.

**Table 2.**

**Planetary Engineering Challenge addressed by Terraformation Technology.**

| | **Terraformation Technology** | | | |
|---|---|---|---|---|
| **Planetary Engineering Challenge** | Industrial | Biogenomic | Nanomic | Orbital |
| Surface Temperature | **x** | | | **x** |
| CO2 Polar Phase | **x** | | | **x** |
| CO2 Regolith Phase | | **x** | | |
| Solar Radiation Ultraviolet | **x** | | | |
| Solar Radiation Insolation | | | | **x** |
| Ecopoiesis | | **x** | **x** | |
| O2 Introduction | | **x** | | |
| N2 Buffer Stability | | **x** | | |
| Ecosystem Homo | **x** | **x** | **x** | **x** |

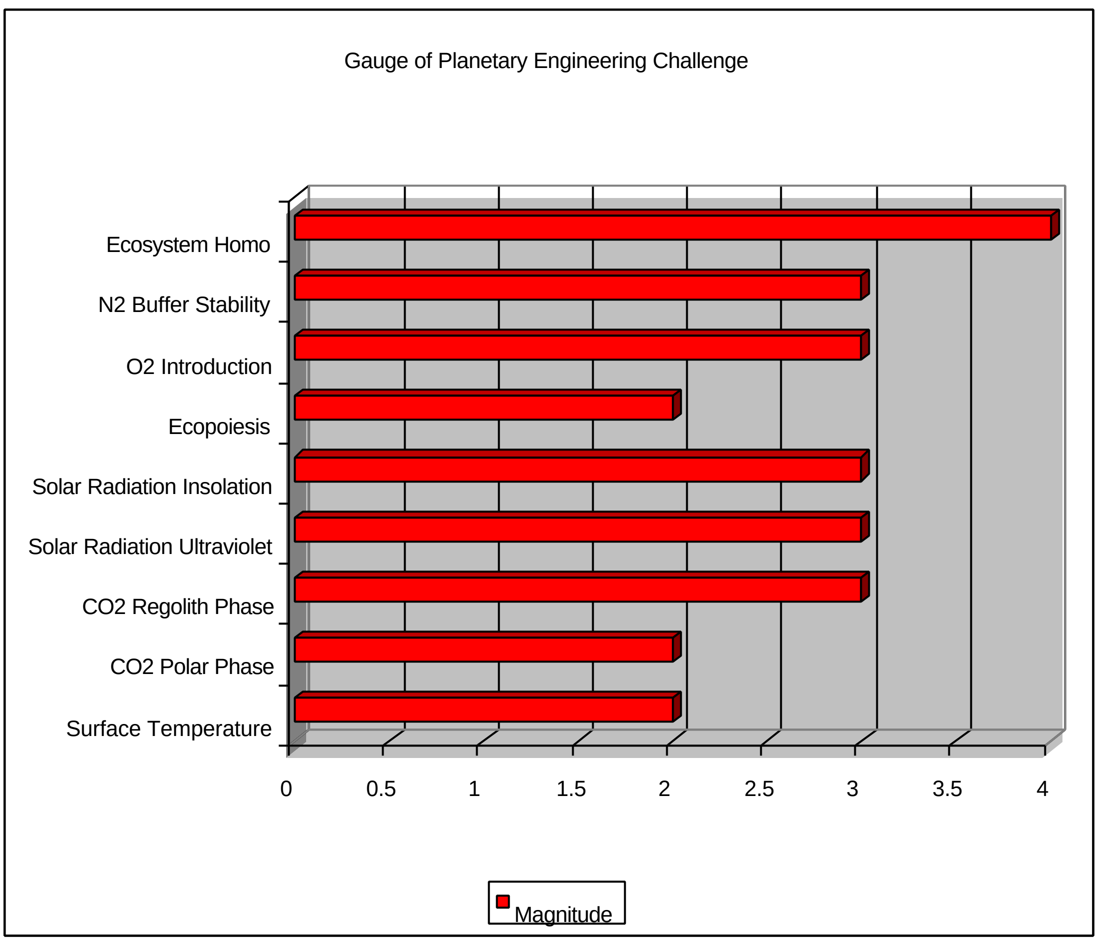
To gauge the level of difficulty posed by each planetary engineering challenge in light of the expectation that one or more terraformation technologies will offer a solution, I have assigned a scalar value to each challenge based on the number of potential solution technologies (0-4) subtracted from the total number of available terraformation technologies (4). The assigned number expresses the magnitude of the difficulty, i.e., the complexity of the planetary engineering challenge. For example, the gauge of the $CO_2$ Regolith Phase challenge is 3 (only one solution technology) and the gauge of the Surface Temperature challenge is 2 (two solution technologies): $CO_2$ Regolith Phase challenge is thus estimated to be an order of magnitude more difficult – the challenge ten times more complex – than the Surface Temperature challenge.

A value of four is arbitrarily assigned to the final challenge, "Ecosystem Homo," because as the final step of a massively complex project it will be intrinsically more complex and difficult to successfully complete than any other stage of the project, irrespective of the enabling technology.

Chart 2 presents my assessment of the gauge values for the entire planetary engineering project.

**Chart 2.**

**Gauge of Difficulty of Planetary Engineering Challenge.**



The highest gauge values can also be considered to represent the areas of highest risk and greatest cost.

The challenges of planetary engineering will be difficult and complex, and there will be much to investigate, analyze, prepare, and create on Mars.  Then terraformation will begin.

# III. The Ethics of Terraformation

## The Mechanisms of Life

Life, wherever it appears, contends for its place in nature. Where life prospers, an ecosystem emerges. As the arena of evolution, the ecosystem reshapes the inertial entropy of nonliving physical systems to form the propagating order of living information.

On Earth, this order, crested by human intelligence, now stands at the threshold of interplanetary expansion.

There are three mechanisms for the introduction of ecosystemic life on habitable zone planets. The first mechanism is local creation,[21] where the planet's own combination of chemical events as yet not well understood by science, mediated by indeterminate environmental factors (perhaps including an exchange of chemistry with other celestial objects such as comets or interstellar gas clouds), gives rise to the self-replicating, self-organizing molecular structures known as life. The second mechanism is remote creation,[22] where life originally created elsewhere by the first mechanism is deposited on the planet by chance catastrophe[23] or inadvertent contamination by visitors.[24] The window of opportunity for the second mechanism to actually introduce life on a planet cannot be very wide, however. The evidence of life on Earth, the only evidence so far of life in the universe, strongly suggests that life, either aerobic or anaerobic, appears wherever and whenever it *can* appear, from rocks under the Antarctic ice to the boiling

[21] My term.
[22] My term.
[23] Although it seems overwhelmingly probable that life originated independently on Earth, and likewise if found on Mars, the potential for cross contamination in one direction or the other cannot yet be scientifically ruled out; recent meteorite discoveries have been construed by some researchers to be further evidence that such a Martian contamination of Earth is possible, however remote.
[24] Great care is taken with spacecraft to prevent this possibility. To whatever extent possible, such care will be taken by early Martian explorers and colonists. Recall that in *The Martian Chronicles*, Ray Bradbury's Martians were carried to extinction by the measles.

waters of deep-sea smokers. It is reasonable to assume that this is also true on Mars.[25] The third mechanism is introduction by terraformation: the intentional modification of an environment and introduction of an ecosystem on one planet by the life of another planet.

During the present era of space exploration every effort has been made to prevent the second mechanism. A future era of planetary engineering may make every effort to achieve the third mechanism.

## Should Humans Terraform Mars?

The broad question of terraformation produces at its extremes two equally powerful responses:

> *No* - because there is life on Mars, or there is the virtually untestable possibility of life on Mars. In a biocentric extension of the Kantian view to Mars, the proposal to terraform Mars faces the crisis of the negative. We can never prove there is no life on Mars, so humans must honor the intrinsic value of Martian life indefinitely.
>
> *Yes* - because human species survival, or recast in terms of terraformation, the survival of Earth-based life, can be insured.[26] The application of the Kantian ethic to some subset of Earth animal and plant species drives the ultimate utilitarian decision to alter the environment, and possibly the ecology, of another planet. The extension of man and Earth-based life beyond a single planet is seen as a long-term guarantee of human existence.

[25] If life has only appeared once in the universe, or appears only *very* rarely (say, once in a galaxy in five or ten billion years), then it seems to me that any and all ethical issues dissolve and the terraformation of Mars becomes imperative, the goal morally indistinguishable from the process of DNA-based reproduction.

[26] This consideration is as much political and sociological as philosophical or scientific. In order to concentrate on the general philosophical issues in the space allotted, I have chosen not to spend much time on terraformation as an act of zealous frontiersmen or desperate exiles.

The ethical question posed by planetary engineering has been raised in serious planetary engineering discussions[27] in a framework that exhibits the juxtaposition of a Kantian dilemma regarding the intrinsic value of life with a strong utilitarian urge toward species survival.

From the perspective of homocentrism, the primacy of humans and the creatures of their dominion (thus I include zoocentrism, the concern for animals of Earth), permits the terraformation of Mars. The Kantian view of man, implicitly valued over any measure of Martian nature, permits him to act in his own interest, and the interests of his dominion as its ruler. The ethical result is the preservation and extension of man and his dominion.

From the perspective of biocentrism, where sanctity of life is the dominant consideration, the prospect of terraformation becomes more problematic. If Mars were as conclusively lifeless as Earth's moon, the biocentrist view would be logically equivalent to the homocentrist and permission to terraform granted without reservation. It is just because we cannot achieve certainty of the negative that the biocentrist must deny permission to terraform Mars, or at the very least, proceed with ecopoiesis and finally complete terraformation with the gravest reservations and caution. In this case, man acts in Kantian justification with a dash of environmental utilitarianism. The shift from ecopoiesis to full terraformation has a precedent in nature: migration from anaerobic life (ecopoiesis) to aerobic life (terraformation) occurred on Earth over a period of some one to two billion years. In the event the planetary engineering project moves forward, [28] the ethical end result is the preservation and extension of Earth-based life at the real or imagined expense of Mars-based life.

[27] Primarily by MacNiven [6].
[28] One can imagine that a serious social and political disagreement over the fate of Mars would attend this course of action.

Homocentrism and zoocentrism generate a strong anthropocentric bias to man and life on Earth. Biocentrism rationally extends the framework of the discussion to a point of view outside Earth.

The moral authorization to terraform Mars is even more in doubt from the perspective of what I will call "conventional" cosmocentrism, where the sanctity of existence itself is honored. In this view, Mars, with or without life, is intrinsically valuable as an object in the universe, and thus ought not be used a means to man's, or life on Earth's, end.

The impasse in the philosophical discussion of planetary engineering "suggests that current ethical theories cannot adequately deal with the moral problems which projects like terraforming or ecopoiesis pose."[29]

To construct an ethically justifiable philosophical foundation for terraformation, we must reevaluate the relationship of humans to life on Earth, and restate the question.

Human life is at the most important hub of the vast living network of inter-related ecological chains that comprise life on Earth. Human activity has become a critical factor in the health of the ecosystem of Earth. To a greater extent than he is often given credit for, or than he sometimes assumes responsibility for, man is the proprietor of his only planet and custodian of life on Earth.[30] In a very real sense, man is the master and representative of life on Earth. Of all the forms of life on Earth, man occupies the role he does because he is the most active – geographically, technologically, and virtually every phase of ecological interactions - sentient form of life on Earth, and the most active *above and beyond it.* Man claims and asserts dominion over life on Earth.[31] It is in this role that man proposes to terraform Mars.

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[29] MacNiven [6], pp. 306.

[30] This fact became generally apparent to a large part of humanity when *Apollo 8* returned the first image of the home planet to its inhabitants in December 1968.

[31] I concede that this proposition is contentious in the extreme, and subject to debate on many levels, but I do not deem that I have the liberty here to fully explore the issue. I use the pejorative term "man," rather than "humanity," to be suggestive of the controversy concerning the human disposition and right to dominate nature. It is my expectation that this controversy will figure prominently in the debates of future

It is here that the leap must be taken beyond the current Earthbound ethical framework. The "conventional" cosmocentric view must be unabashedly revised to recognize and esteem what is most rare[32] in the cosmos: mind, which mysteriously emanates from life – the brief localized[33] victory of information over entropy. This is not a retreat to homocentrism, rather it is a step toward the mature human recognition[34] of man's role as an instance of the cosmos aware of itself. It is the Kantian view come full circle.

Recent downward reassessments of the frequency of life and particularly intelligence in the universe have renewed the urgency of the recognition of the importance of Earth-based life.[35] If, as now seems probable, life is much more rare in the galaxy than previously optimistically supposed and sentient life rarer still, the argument to insure the long-term prospects for life against the vicissitudes of a rock-filled inner solar system carries much more weight.

The ethical basis for planetary engineering and the process of terraformation can now be restated. We must respect sentient life where and when we find it.

Can we *prove* there is no sentient life on Mars? Though difficult,[36] it should be a simpler task than proving that there is no life on Mars.

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space faring and terraforming societies. Humanity will probably not cross the interstellar threshold until the matter is settled.

[32] There is no scientific evidence to the contrary.

[33] As I believe John Kenneth Galbraith assessed the Keynesian view, "In the long run, we are all dead." We will not address here the metaphysical implications of Chardin's thesis, but it is charged with as much hope for the final destiny of man as the notions of Socrates in the *Phaedo*.

[34] Awareness of self is a profound signature of mind, just as replication of self and organization of self are profound signatures of life.

[35] Researchers such as Benjamin Zuckerman of UCLA (*Extraterrestrials: Where Are They?* Cambridge Press, 1995) persuasively argue that the speculative values commonly used in Drake's Equation yield unrealistically optimistic results. Drake's Equation is N=R*fs*fp*ne*fl*fi*fc*L, where R=star formation rate, fs=suitable sun fraction, fp=planet fraction, ne=suitable planet factor, fl=life fraction, fi=intelligent life fraction, fc=radio fraction, L=technological lifetime. Previous suppositions regarding parameters ne, fl, and fi are now scrutinized with increasing skepticism based on new observations of extra-solar planets.

[36] Science fiction from Stanislaw Lem's *Solaris* to Kenneth Gantz's *Not in Solitude* notwithstanding.

On Earth, man sees mind in most if not all mammals, some if not most insects, but he does not see mind in flora; nor does he see it in bacteria or viruses, where alternate explanations for complex behavior are accepted. On Mars, man must conscientiously seek sentience in any life that he discovers there, and investigate any claim of sentience meticulously. A mistaken negative assessment would be at the very least morally catastrophic for humanity. If man does not detect mind on Mars, after a thorough effort to discover it, then he may conclude that there is no mind on Mars. Man's authority to draw this conclusion is his science, *his mind*, on Mars.

Humanity of the interplanetary era will then have a basis upon which to assert a fresh proposition as the foundation for a neo-cosmocentric[37] ethics where sanctity of mind holds primacy. *Sentient life from Earth is to become the terraformer of non-sentient worlds.* If there is no mind arising from life on Mars, then even in the presence of life, or the mere possibility of life, the ethical path for terraformation is clear. The human commitment to terraform Mars meets this neo-cosmocentric responsibility. The ethical end result is the extension and additionally insured preservation of life in the solar system.

The moral consequence of terraformation confers significant meaning to human interplanetary culture. The terraformation of Mars represents the genuine expansion of sentient life from Earth into the solar system. Life from Earth becomes independent of the fate of the Earth. Terraformation implies more than human survival: it is the evolutionary extension of life from Earth beyond the Earth. [38] Terraformation is itself an act of nature.

***-Peter Ahrens December 2003***

[37] My term.
[38] To use the language of Lovelock and Chardin, the terraformation of Mars is the expansion of *Gaia* (Lovelock) and the extension of the *Noosphere* (Chardin) beyond Earth.

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