Terraforming, or planetary engineering, is the process of altering the climate of a planet to be more hospitable to life and human exploration. Of all the bodies in the solar system, Mars is by far the best candidate. Let's look at how that would work:

To understand how Mars might have a habitable future, it's important to understand a bit about Mars' geological history. Mars was once a warm, wet planet.

<table>
<thead>
<tr>
<th>Amazonian (current)</th>
<th>Hesperian (intermediate age)</th>
<th>Noachian (warm, wet period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today</td>
<td>3.7 to somewhere between 1.7 and 3.0 billion years ago</td>
<td>4.1 to about 3.7 billion years ago</td>
</tr>
<tr>
<td>Cold, dry</td>
<td>Heavy volcanic activity and massive water flow</td>
<td>Heavy asteroid bombardment and abundant surface water</td>
</tr>
</tbody>
</table>

It is this unique history that makes Mars such an attractive candidate for terraforming. Unlike the other bodies in the solar system, Mars has a history (ancient though it may be) of being far more Earthlike than anywhere else in the solar system short of Earth itself.

Mars, with its 24 hr 37 minute day, relatively abundant water ice and history of warmer wetter conditions seems more within the grasp of near future human civilization to terraform.

So the good news is that much of the material we need to give Mars a thicker, warmer atmosphere are still present on its surface and buried in its regolith. Despite these promising circumstances, however, it's clear that one does not simply walk into terraforming Mars.

In his definitive text, Terraforming: Engineering Planetary Environments, Martyn Fogg laid out five critical challenges:

1. The surface temperature must be raised
2. The atmospheric pressure must be increased
3. The chemical composition of the atmosphere must be changed
4. The surface must be made wet
5. The surface flux of UV radiation must be reduced

**Basic Strategy**

It is possible that mechanical methods could be employed to keep Mars in a terraformed state. However, a well-designed, self-regulating global
biosphere will be much more preferable and effective, as it will not require constant maintenance.

Taking this as our eventual goal and working backwards, a basic series of steps can be determined. Note the inclusion of a step that is frequently ignored or glossed over in terraforming discussions, namely nitrogen importation.

![Diagram showing steps in terraforming]

Terraforming can thus be simplified to 3 primary engineering tasks:

1. **Increasing Temperature**
2. **Atmospheric Engineering**
3. **Biosphere Construction**

We will focus on the third stage: Biosphere Construction, specifically with the use of microbes.

**Biosphere Construction**

Biological elements can be added to Mars as soon as liquid water is available, which may be right from the start. There may be pools, streams or aquifers below the Martian surface where temperatures are higher, and if these places can be accessed, new organisms can be introduced as soon as we decide to begin terraforming.

The Martian biosphere will be built by starting at the bottom of the food chain and working up.

This suggests a 3-phase approach:

1. **Microbes.** With the basic nutrients available, a microbial ecosystem can be designed and implanted. Its primary role is to prepare the regolith for global introduction of photosynthetic organisms.
2. **Plants.** These serve the important function of converting the atmosphere from carbon dioxide to oxygen.
3. Animals. Most animals will not be added until terraforming is complete, although worms, fish and perhaps others may be introduced earlier.

**Microbial Martians**

Genetics will be much more advanced at the time of terraforming. Although some terraformers have sought to identify terrain extremophiles that can potentially survive on the Martian surface, mere survival is not enough. What is really necessary is to design organisms that will create a specific required effect.

The primary role of the “first wave” of aquatic microbes will be to photosynthesize. For non-aquatic microbes, it will be the addition of nitrogen compounds to the soil in order to prepare the ground for plants. As mentioned earlier, one possible secondary role for terrestrial microbes could be to produce methane, a useful greenhouse gas.

New microbes to fulfill this role can be created using genetic material from a variety of sources, including:
- a) organisms that perform these roles on Earth
- b) extremophiles with traits suited to Mars
- c) existing Martian life

Beginning with engineered organisms, a program of ‘managed evolution’ combining genetic engineering methodologies with natural evolutionary processes will produce a multitude of new organisms well-suited to Mars’s environment, which would perform a key role in the terraforming process.

**Extremophiles**

Extremophiles are often cited as being a good choice for early Martians. There are several categories with genetic traits that would be useful on Mars:

- halophiles (salt-loving)
- acidophiles (acid-loving)
- cryophiles (aka psychrophiles – cold-loving)
- xerophiles (dryness-loving)
- oligotrophs (adapted to lack of nutrients)
- radioresistant (adapted to high radiation levels)

Some of the most popular extremophiles discussed (Hiscox & Thomas, 1995; Budzik, 2000; Slotnick, 2000) in the context of terraforming are:
1. *Deinococcus radiodurans*. This is a polyextremophile with excellent DNA-repair mechanisms, capable of surviving in high radiation levels, and also resistant to peroxides and other oxidisers, desiccation and cold.

2. *Chroococcidiopsis* sp. A polyextremophilic cyanobacterium adapted to salty, arid conditions and capable of withstanding extremes of temperature.

3. *Matteia* sp. This is a desiccation-resistant cyanobacterium that can dissolve through carbonate rock, able to liberate carbon dioxide as well as fix nitrogen.

4. Nitrogen processors
Azotobacter is a type of soil bacteria that fixes nitrogen. Present Terran versions would not survive on the Martian surface, but combined with radioresistant, cryophilic and other genetic traits, *Azotobacter radiodurans* (for example) may perform the important task of adding ammonia to the soil.

5. Methanogens
Methanogens are microorganisms that produce methane. Therefore, methanogens could be useful if we decide that biological methane production would be a safe and useful method of warming the planet. On Earth, methanogens are typically found underground, possibly because of the high oxygen levels on Earth’s surface. Perhaps on Mars, while O₂ levels are low, some extremophilic methanogens could thrive on the surface. It may be possible to engineer methanogens that do not die in the presence of oxygen, and which can remain on Mars in the long term—one possible way to maintain higher temperatures after CO₂ levels have dropped.

**References**

4. Terraforming Mars Shaun Moss 2006
   www.marspapers.org/papers/Moss_2006_1.pdf