Terraforming and its Potential Future Application on Mars

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One of the greatest quests in astronomy is to discover planets that have the right parameters to sustain life as we know it. So far, only a handful of planets discovered fall into this habitable zone, the distance from the star that provides the conditions for life to survive. The Earth falls into this category, providing the conditions needed for life to form, but there are many other factors on Earth that enable the existence of life, such as an atmosphere and liquid water. Today astronomers look at planets in our solar system not only for extraterrestrial life but also Earth-like conditions that would allow for human survival. Humans have become an abundant species, with a population over seven billion individuals and increasing at a much faster rate than any time in the past; as a result almost every environment on Earth has felt the effects of human civilization (Cohen, 1995). Overpopulation has become a serious problem, as no one knows how many humans the Earth can truly sustain, even with technological advances. To provide room for this growing population, many scientists have proposed colonization of other planets in our solar system (Sagan, 1961; Landis, 2003; Zubrin and McKay, 1993; Friedman and Ocampo-Friedman, 1995; Moss, 2006). The problem is that none have conditions similar enough to Earth to allow humans to live on these planets, and other planets in the galaxy are unreachable by current technology. Scientists proposed a simple solution: terraforming, the process of transforming a planet so that it resembles Earth and can support human life (Sagan, 1961; Landis, 2003; Zubrin and McKay, 1993; Friedman and Ocampo-Friedman, 1995; Moss, 2006). While this is mostly still in the theoretical stages, humans have already changed the environment of some planets in the solar system.

Terraforming is not a new concept as it has appeared in science fiction books countless times (Moss, 2006). Recently terraforming has begun to look more like a reality, though no planet has ever been terraformed or even attempted. It was first suggested by Carl Sagan in 1961, who proposed that Venus could be seeded with algae that would reduce the atmosphere and produce oxygen (Sagan, 1961). Later studies found that the atmosphere of Venus, while containing many of the elements important to life, such as carbon, nitrogen, oxygen and hydrogen, also contains sulfuric acid droplets which make it inhospitable to most life from Earth (Landis, 2003). While Venus is considered Earth's sister planet, it is an excellent example of a runaway greenhouse effect that has resulted in the surface reaching temperatures of 735^{o} K and an atmospheric pressure of 96 Bar, where Earth's atmospheric pressure at sea level is 1 Bar

(Landis, 2003). Instead focus shifted over to Mars being the best potential candidate (McKay, 2007). Earth and Mars share many similarities; they both rotate around their axes at about the same rate, as well both have axes that tilt to give both of them seasons (Zubrin and McKay, 1993). Studies of the Martian landscape show that Mars may have at one point had liquid water, however what is left of it is frozen at the southern pole due to Mars having a surface temperatures around 130^{o} K where Earth has a surface temperature of 287^{o} K (Zubrin and McKay, 1993; Moss, 2006; Landis, 2003). The main problem with Mars being a planet that could sustain human life is the lack of a thick atmosphere, as the Martian atmosphere has only about one percent the pressure of Earth's at sea level (Zubrin and McKay, 1993). Many scientists have proposed different ideas on how generate an atmosphere using greenhouse gases. The most widely considered idea proposed is to use the same greenhouse gases that pollute the Earth to warm Mars, using factories that would produce greenhouse gases such as carbon dioxide or hydrocarbons, which would have a similar effect as is seen on Earth (Zubrin and Mckay, 1993; Moss, 2006). The basic idea is that the gases would make the atmosphere thicker, which would then trap sunlight raising the temperature over time as well as filtering out solar radiation. The hope is that like Earth, carbon dioxide was trapped in the water and is now frozen at the poles. So as the temperature increases, the ice caps would melt, releasing the frozen carbon dioxide, resulting in a positive feedback loop (Zubrin and McKay, 1993).

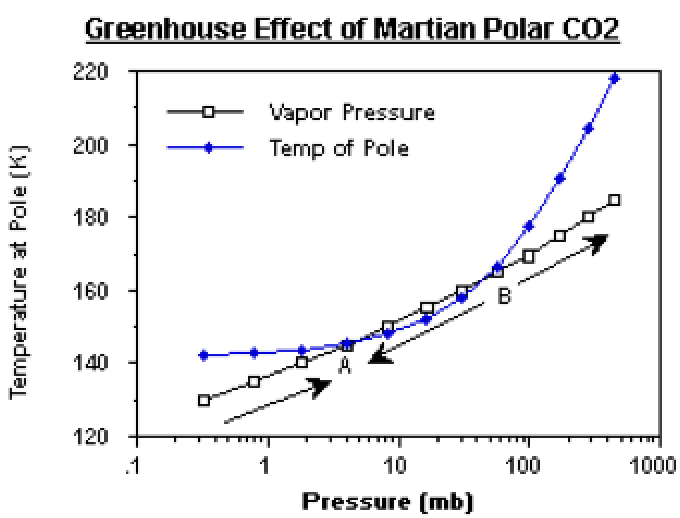

Figure 1: Greenhouse effect on Martian Polar CO_2 (Zubrin and McKay, 1993). This figure illustrates how vapor pressure and temperature are both key to causing a greenhouse effect on Mars. The black line on the graph is the vapor pressure of CO_2 in the atmosphere as a function of polar temperature while the blue line is the temperature of the poles as a function of the vapor pressure. Point A represents the current stable equilibrium on Mars between the temperature and pressure while point B is an unstable equilibrium state. If the line for the temperature of the poles is below the line for the vapor pressure then the equilibrium will shift left, back towards the stable A. However, if the temperature is greater than the vapor pressure then the equilibrium will move to the right. It is only once these two factors have passed point B that a runaway greenhouse effect will occur on Mars. If this is not achieved the planet will return back to its stable equilibrium (Zubrin and McKay, 1993).

This figure illustrates exactly how much CO_2 would need to be put in the atmosphere in order to attain this runaway greenhouse effect which would result in a self-sustaining atmosphere. Scientists can see the effect carbon dioxide has on atmospheres based on Earth. Earth's first atmosphere mostly consisted of carbon dioxide and nitrogen released by volcanoes (Kasting and Siefert, 2002). Today Earth's atmosphere contains very little carbon dioxide, but excess amounts of carbon dioxide being released into the atmosphere are causing an increase in temperature (Kasting and Siefert, 2002). Due to its small size, Mars has no volcanism or plate tectonics to recycle materials, so factories would be used in place of volcanoes (McKay, 2007). The goal would be to create an atmosphere that would be self-sustaining and allow photosynthetic organisms to grow, which would produce oxygen and potentially allow humans to live on the planet with minimal assistance from technology (Friedman and Ocampo-Friedman, 1995).

There are many other different proposals for how to terraform Mars but what remains consistent is that any of them would completely change the face of the planet. Some ideas include establishing orbiting mirrors around Mars to reflect sunlight and raise the surface temperature, or purposefully crashing an ammonia filled asteroid into Mars (Zubrin and McKay, 1993; Moss, 2006). There are also many ways in which terraforming attempts could fail. One example mentioned is that it is currently unknown how much carbon dioxide is present in the poles of Mars, if there is too little then Mars will not be able to attain a self-sustaining atmosphere and will return to its original state (Moss, 2006). Even estimates of how long this process would take for humans to be able to survive on the surface vary based on current and future technologies (Moss, 2006; McKay, 2007).

Humans have already changed the landscape of Mars unintentionally. Until recently, planets in the solar system have been free of human influence. This all changed when we began exploring the objects in our solar system, starting with the moon (Karlin, 2001). Whatever is sent into space is guaranteed to host a variety of microorganisms, even though precautions are taken to keep them clean. The Curiosity probe sent to Mars was found to have 377 strains of 65 bacteria species even after decontamination procedures (Madhusoodanan, 2014). It is unsure whether these bacteria survived the trip, however the probes that make it to the surface of the planets leave some of these microbes behind, and in the lab it was found that these bacteria could survive many of the conditions they would be exposed to during the trip (Madhusoodanan, 2014). Even while dormant or dead, the planet has now been contaminated by Earth life and changed forever. Thus the UN established a treaty to try and prevent planets from being contaminated by Earth life. Many scientists consider this a major concern in the search for life as there is the potential of finding Earth microbes and mistaking them for extraterrestrial life. While multicellular organisms like humans would not be able to survive the vacuum of space or the hostile conditions of the planets in the solar system, many microorganisms, such as *Deinococcus radiodurans* can survive dehydration, cold, vacuum, acid and high levels of radiation (Daly, 2009). While these bacteria were not found on the Curiosity probe they are an excellent example of bacteria that could survive the hostile conditions of extraterrestrial planets. These organisms are not active however, once in space they enter a dormant state, a type of hibernation where they become active once the conditions become favorable (Friedman and Ocampo-Friedman, 1995). Life aside, the planets have still been contaminated by machinery and material that has never been present in the environment before (Debus, 2005). This is another way humans are changing the environment of other planets, whether it is the exhaust from the jets or debris from landing equipment (Debus, 2005). Even the rovers eventually die and are left on planets, becoming part of their environment (Debus, 2005).

Humans have already altered many aspects of the natural world of Earth, and as a result, Earth is much different than what it was previously. Now humans are reaching the point where they can significantly change the environments of worlds that have never been exposed to human influence. This brings up the notion whether it is ethical to completely change the environment of a planet through terraforming or whether it is imperative that the planets remain pristine (McKay, 2007). With the increasing population and limited resources of Earth, it seems inevitable that terraforming will become an important part of the future. Based on the papers reviewed (McKay, 2007; Moss, 2006), use of greenhouse gas producing factories to terraform Mars seems like a plausible approach with current technology and that the environment of Mars could be further enhanced with the use of photosynthetic organisms. If this technology is successfully used on Mars, it could then be potentially applied to other planets and moons within the solar system, however different processes would have to be used for the range of conditions found in the solar system.

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