International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 12 Issue 7, July-2023, Impact Factor: 7.957

Greening the Red Planet: Strategies for Cultivating Plants on Mars

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ABSTRACT

When people move to Mars or the moon, they will need to find food there. Food can come in via plane. Plant cultivation on-site, ideally in native soils, is an alternative. We present the results of the first large-scale controlled experiment to test the viability of plant growth on Mars and the moon. The findings demonstrate that plants can sprout and develop on both simulated Martian and lunar soil for a duration of 50 days without the addition of nourishment. In comparison to moon regolith simulant and even somewhat better than our control river soil, growth and blooming were significantly improved on Mars regolith simulant.Systems to supply humans with food, oxygen, and water are needed for future manned flights to Mars or for the colonisation of the red planet. If they were to be grown on Mars, plants would be able to generate them. The factors that need to be taken into account for a greenhouse to survive on Mars are water, soil, atmosphere, light, temperature, design, and plants. On Mars, water is found in the frozen soil as ice. Utilising heat, microwaves, or humidifier-style equipment can extract water.

Keywords: Mars, Greenhouse, Water, Martial Soil, Atmosphere, Temperature, Light, Greenhouse Attributes

INTRODUCTION

The mineral make-up of the soil on these solar bodies has been revealed via explorations of the moon and mars. They also include significant amounts of regolith’s, which resemble sand. With the possible exception of reactive nitrogen, both soils appear to contain sufficient amounts of all required minerals for plant growth. One of the fundamental nutrients required for practically all plant growth is reactive nitrogen (NO_3, NH_4) [1]. The mineralization of organic materials is the primary source of reactive nitrogen on Earth. Although they both contain carbon, the moon and Mars both lack organic stuff [2–6]. One of the fundamental nutrients required for practically all plant growth is nitrogen in reactive form (NO_3, NH_4).Mars is a target for astrobiology not only because of its proximity to or likeness to Earth, but also because, billions of years ago, Mars had liquid water and an environment similar to that of the Earth, where life first arose. However, it is currently almost hard for life to exist on the red planet. It is extremely difficult to survive on Mars due to the lack of liquid water, extremely low temperatures, a low-pressure atmosphere with high levels of carbon dioxide, a gravity that is one-third that of the Earth, high levels of radiation on the surface, and a lack of organic nutrients.

Because of its proximity to the Sun and the makeup of its atmosphere, Mars has a good chance of supporting human life in the future. The ability to support and sustain plant growth on Mars is an important element to consider. This would be accomplished by constructing a greenhouse that could alter Mars' atmosphere to resemble Earth's.Due to this interest, manned missions to Mars and, additionally, the potential colonisation of the red planet call for systems that will primarily supply oxygen, water, and food for human people' metabolic needs. These processes are largely made possible by plants on Earth, whether through CO2 absorption and O2 emission, water purification through transpiration, waste product recycling through mineral nutrition, or as a source of food.

Water on Mars

The availability of water on a planet is essential for supporting plant life and, eventually, a human population. Fortunately, in 2015, NASA’s Mars Reconnaissance Orbiter (MRO) found the most concrete evidence to date that liquid water flows intermittently on present-day Mars. The water could, however, be salty, which results in a lower freezing point. Magnesium perchlorate, magnesium chlorate, and sodium perchlorate are probably the main ingredients in these hydrated salts [7].

Although it was previously thought that the northern and southern icecaps of Mars were mostly made of dry ice, they are actually almost totally made of water ice. High-resolution thermal pictures from Mars Odyssey and Mars Global Surveyor were used to make this discovery. The south polar cap of Mars had circular pits with flat floors that ranged in size from 200 to 1000 metres in diameter and were 8 metres in diameter. Every year, their caps expand by 1 to 3 metres. Images from Mars Odyssey show that the lower material warms up, much like water ice would during a Martian summer, which shows that these caps are made of water and not dry ice [8].

Fig. 1. The history of water on Mars and how it varies over time

Growing Crops on Mars

It is difficult to foresee what we will or won't be able to do after we land on Mars. Watney's scientific approach holds up, nevertheless, in terms of the chemistry used in The Martian. Hawaii's volcanic soil, which is renowned for its resemblance to Martian soil, has been used by scientists to undertake plant studies that simulate Martian conditions. These tests revealed that plants can flourish in these soils.Future Mars explorers will also need to think about other factors when cultivating plants there. As was previously established, the majority of Mars' atmosphere is carbon dioxide, and plants require this gas in the same way that humans require oxygen to breathe.

Additionally, research indicate that less water may be needed on Mars than it does on Earth for plant irrigation. This is due to the fact that water would flow through Martian soil differently due to the gravity of the Red Planet, which is around 38% more than that of Earth. In other words, something would feel three times as light on Mars as it does on Earth. As a result, because of Martian gravity, soil can contain more water than it can on Earth, and water and nutrients would also drain from the soil more gradually.On Mars, certain factors would make it challenging for plants to flourish. For instance, life is challenging to support on Mars due to its intense cold. That planet receives significantly less sunlight and heat than the Earth does. This is due to Mars' greater distance from the sun—about 50 million miles—than Earth. In addition, the Earth's atmosphere, which keeps our planet warm, is thinner than the atmosphere of Mars.

Martian Soil

Martian soil, also known as regolith, refers to the loose material covering the surface of the planet Mars. It is composed of a mixture of rocks, dust, sand, and other particles. Martian soil differs from Earth soil in several ways due to the unique conditions on Mars.

Composition

The composition of Martian soil is primarily silicate-based minerals, including basalt, pyroxenes, olivine, and feldspar. These minerals are similar to those found on Earth but may have undergone weathering processes unique to Mars. Martian soil also contains significant amounts of iron oxide, giving it a reddish colour and earning Mars the nickname "the Red Planet."Unlike water, there is a bountiful supply of readily available soil on Mars. With the exception of reactive nitrogen, which is an essential component for plant growth, Martian soil fortunately already has the majority of the nutrients needed for plant growth [9]. The nitrogen atoms that are now present on Mars must be "fixed" or "separated" before they may become "reactive." Without being fixed, it will continue to exist as nitrogen gas and won't respond, which prevents good plant growth [10].A nitrogen "fixer" like cyanobacteria makes use of an enzyme that collects nitrogen gas and changes it into reactive nitrogen [11]. Martian soil retains water exceptionally effectively, which helps plants grow more successfully because the soil won't quickly dry out.

Additionally, it has been discovered that the soil on Mars contains many nutrients, including salt, potassium, and magnesium [12].

Water Content

One of the key differences between Martian soil and Earth soil is the lack of significant amounts of liquid water. While there is evidence of past water activity on Mars, the planet's current surface conditions are too cold and the atmospheric pressure is too low for liquid water to exist. However, there may be traces of water molecules bound within the soil or as ice deposits in certain regions.

Chemical and Biological Considerations

Martian soil has been the subject of scientific interest and exploration missions because of its potential to support life or provide insights into the possibility of past or present life on Mars. The soil's chemical properties, including its pH and nutrient content, are essential factors in determining its habitability. Researchers have found that Martian soil contains some necessary elements for life, such as carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulphur.

ATMOSPHERE

Table 1 compares the atmospheric composition of Earth and Mars and reveals how drastically different they are from one another. Despite these differences, Mars has the ability to support plant life because of its high carbon dioxide concentration, which is necessary for photosynthesis. Water and sunlight energy are needed for photosynthesis to occur. Both are not particularly plentiful on Mars.Because Mars' atmosphere is 100 times thinner than Earth's, it is challenging to collect solar energy. There are other ways to increase the density of the atmosphere, including employing orbiting mirrors to melt the north and south poles, building factories to produce additional greenhouse gases, or slamming ammonia-heavy asteroids onto the planet [13].

Creating a suitable atmosphere for plant growth on Mars is a complex challenge. The Martian atmosphere is very thin and consists mainly of carbon dioxide (CO_2) with traces of other gases such as nitrogen, argon, and oxygen. To create an environment conducive to plant growth, several factors related to the Martian atmosphere need to be addressed:

1. Atmospheric Pressure

The average surface pressure on Mars is about 0.6% of Earth's atmospheric pressure. Plants require a certain level of pressure to maintain the integrity of their cellular structure and to allow for processes like transpiration. Therefore, it would be necessary to increase the atmospheric pressure to a level that supports plant growth.

2. Oxygen Levels

The Martian atmosphere contains only a trace amount of oxygen (around 0.16%). For plants to thrive, an adequate supply of oxygen is crucial. Generating and replenishing oxygen would be necessary to sustain plant respiration and the respiratory needs of other organisms.

3. Carbon Dioxide

While the Martian atmosphere is predominantly composed of carbon dioxide, it is not directly usable by plants in its current form. Plants require higher concentrations of CO_2 for efficient photosynthesis. It would be necessary to extract and concentrate carbon dioxide from the Martian atmosphere to provide plants with a suitable source of this essential gas.

4. Trace Gases

The Martian atmosphere contains other gases, such as nitrogen and argon, albeit in low concentrations. These gases are required for various biological processes. However, the levels may need to be supplemented to ensure optimal plant growth.To create a habitable atmosphere for plants on Mars, various proposals have been suggested, including:

a) Terraforming

This involves the deliberate modification of Mars' atmosphere on a planetary scale. The idea is to introduce greenhouse gases into the atmosphere, such as fluorocarbons or sulphur hexafluoride, to trap heat and increase the temperature. This process would require significant resources and long-term planning.

b) Controlled Environments

Instead of modifying the entire Martian atmosphere, it may be more feasible to create enclosed habitats or controlled environments for plant growth. Greenhouses equipped with systems to regulate temperature, pressure, oxygen, and carbon dioxide levels could provide a suitable environment for cultivating plants.

TEMPERATURE

The temperature required for growing plants on Mars is a crucial factor to consider, as it directly affects their survival and growth. Plants have specific temperature ranges in which they can thrive, and deviations from those ranges can have detrimental effects. Here are some considerations regarding the temperature requirements for plant growth on Mars:

1. Optimal Temperature Range
Different plant species have different optimal temperature ranges for growth, typically between 20°C to 30°C (68°F to 86°F). Within this range, plants can carry out essential processes like photosynthesis and nutrient absorption most efficiently. However, it's worth noting that specific plants may have varying temperature requirements.

2. Daytime and Night-time Temperatures
Mars experiences significant temperature variations between its daytime and night-time. Daytime temperatures near the equator can reach around -20°C (-4°F) during the warmest parts of the day, while night-time temperatures can drop as low as -80°C (-112°F). These extreme temperature fluctuations pose challenges for plant survival.

3. Temperature Regulation
Providing a stable and controlled environment is crucial for plant growth on Mars. Greenhouse structures or enclosed habitats can help regulate temperature by insulating plants from the extreme external conditions and providing heating systems when needed. These controlled environments allow for maintaining temperatures within the optimal range for plant growth.

4. Microclimate Considerations
Local microclimates can also influence temperature conditions on Mars. For instance, areas near geothermal features or regions with high thermal inertia, such as rocky outcrops, may experience more moderate temperature conditions. Selecting suitable locations and designing habitats accordingly can help optimize temperature conditions for plant growth.

5. Solar Radiation
Mars receives less sunlight compared to Earth due to its greater distance from the Sun and its thin atmosphere. However, sunlight is still crucial for photosynthesis and plant growth. The reduced solar radiation on Mars necessitates maximizing light exposure and possibly using artificial lighting systems to supplement natural sunlight.The environment's temperature, in addition to the characteristics already mentioned, is crucial to the success of plant growth on Mars. Figures 2 and 3 show how two rovers dispatched to Mars, Spirit and Opportunity, have been instrumental in estimating the temperature on Mars. The average summertime temperature on Mars was found to be between 30 and 35 degrees Celsius between the two Rovers.16 The temperature ranged from negative 90 to 80 degrees Celsius on average during the winter, with a low of negative 110 degrees Celsius. Since Spirit was farther away from the equator than Opportunity, there was a difference in temperature, as shown in the second figure [14].

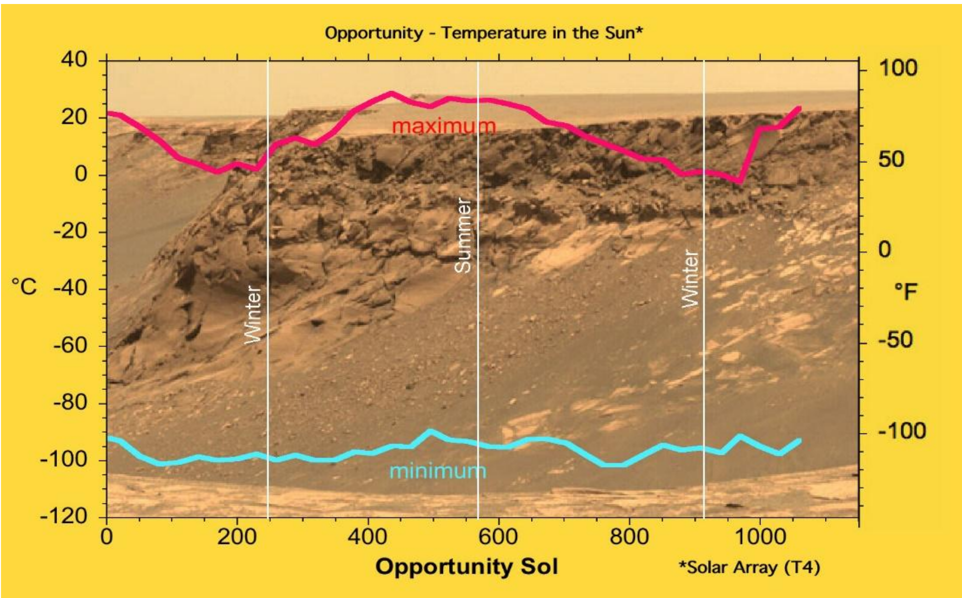

Fig. 2. Source: http://mars.nasa.gov/mer/spotlight/ 20070612.html. Credited to: NASA

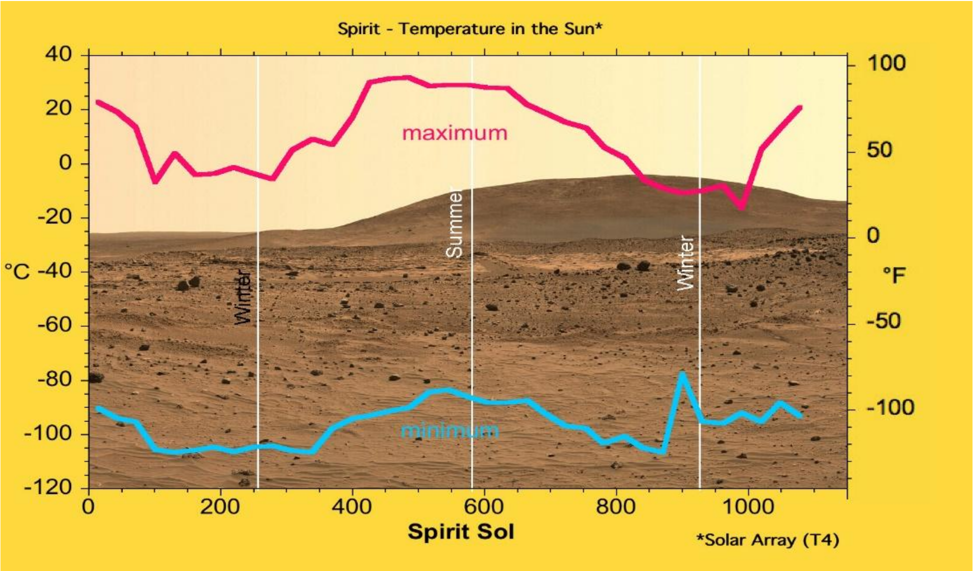

Fig. 3. - Source: http://mars.nasa.gov/mer/spotlight/ 20070612.html. Credited to: NASA

Light

It should come as no surprise that sufficient light is necessary for plants to develop healthily in any environment. Mars receives almost half as much sunlight as Earth does since it is farther from the Sun [15]. Figures 4 and 5 illustrate how the light intensity on Mars and Earth are different.

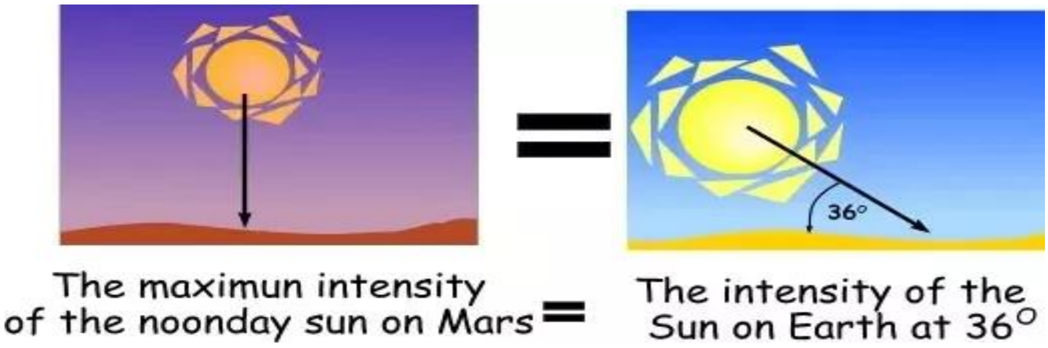

Fig. 4. The maximum intensity of the Sun at noon on Mars is equal to the intensity of the Sun on Earth when it is 36 degrees above the horizon. Source: http://resources.yesicanscience.ca/tomatosphere/final/trans_irradiance2.html

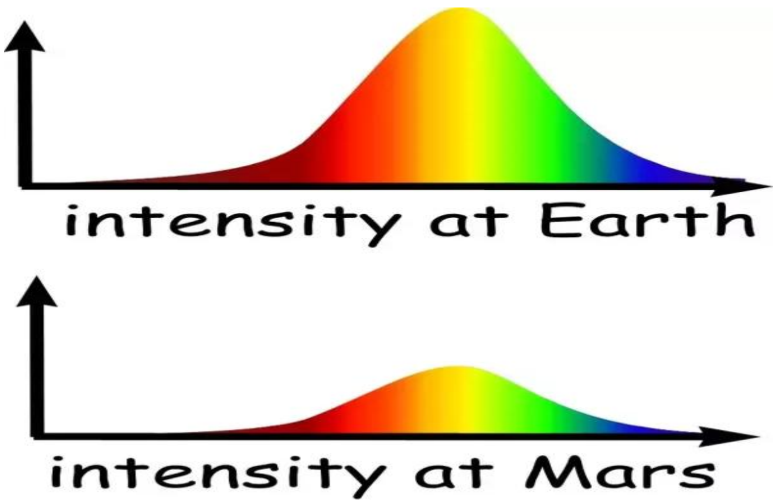

Fig. 5. Spectra of Sun's light on Earth compared to Mars. Source: http://resources.yesicanscience.ca/tomatosphere/final/trans_mars_sun.html

According to Figure 4, the highest amount of sunshine on Mars at noon is almost equivalent to the amount of light experienced on Earth when the sun is just 36 degrees above the horizon [16]. The spectra of the Sun on Earth and Mars are contrasted in Figure 5. Each graph has the same shape, however they all varied in height. Additionally, each spectra's area is related to the energy of the sun. This presents a challenge for Mars-based plant cultivation. The slow rate of photosynthesis and decreased growth, development, and production of a plant are both caused by the low solar energy levels reaching Mars [17]. Food production on Mars will need to be supplemented by greenhouse-grown crops for the optimum yield.

GREENHOUSE ATTRIBUTES

A greenhouse will need to be built in order to overcome the unfavourable conditions listed above in order to realise the objective of cultivating plants on Mars. The primary factors that will need to be changed are the water, atmosphere, temperature, and illumination, as previously said. Before being utilised in the greenhouse, the water needs to be collected and desalinated. A greenhouse's atmosphere can be changed using irrigation systems and carbon dioxide generators. A multi-mission radioisotope thermoelectric generator (MMRTG) could be utilised to keep the greenhouse at a consistent temperature. This employs a nuclear battery with the ability to transform heat into power.Building greenhouses on Mars would be crucial for creating controlled environments to support plant growth and potential colonization efforts. Here are some important attributes that would be considered when designing greenhouses on Mars:

1. Structural Integrity

Greenhouses on Mars would need to be structurally robust to withstand the harsh Martian environment, including extreme temperature variations, high radiation levels, and potential dust storms. The structures would likely be constructed using durable materials such as reinforced metals or advanced composites.

2. Insulation

Insulation would be essential to regulate the internal temperature of the greenhouse. Adequate insulation would help protect the plants from the extreme cold temperatures on Mars, as well as minimize heat loss during the frigid Martian nights. Materials with high insulating properties, such as foams or advanced insulating materials, would be used.

3. Radiation Shielding

Mars has a thinner atmosphere than Earth, which means it provides less protection against harmful solar radiation. Greenhouses would need to incorporate radiation shielding materials, such as thick layers of soil or specialized coatings, to minimize the impact of radiation on plants and humans inside the structure.

4. Lighting Systems

Given the reduced sunlight on Mars, supplemental lighting systems would be crucial for providing the necessary light energy for plant growth. LED (light-emitting diode) technology is commonly used in controlled environment agriculture on Earth, as it allows for efficient energy consumption and targeted light spectra that can optimize plant growth.

5. Atmospheric Control

Maintaining the right atmospheric conditions inside the greenhouse would be vital. This includes controlling temperature, humidity, and carbon dioxide levels to ensure optimal plant growth. The greenhouse would likely have environmental control systems with sensors, heaters, coolers, humidifiers, and carbon dioxide injection systems to regulate these factors.

6. Water Management

Water is a precious resource on Mars, and efficient water management systems would be necessary. Greenhouses could incorporate technologies for water recycling, moisture capture from the atmosphere, or even extraction of water from Martian ice deposits. This would ensure a sustainable water supply for irrigation and plant hydration.

7. Soil Substrates

Martian soil would require modification and supplementation to support plant growth. Greenhouses might utilize a combination of Martian regolith and specially formulated soil substrates that provide the necessary nutrients and structure for plant roots to anchor and access essential resources.

8. Containment and Biosecurity

To prevent contamination of the Martian environment and ensure biosecurity, greenhouses would need to be designed with measures to contain any potential biological material brought from Earth. This would help avoid unintended interactions between Earth and Martian ecosystems.Designing and constructing effective greenhouses on Mars would require innovative engineering solutions and leveraging the latest technologies. Greenhouses serve as vital platforms for conducting plant research, providing sustenance for human crews, and establishing the foundation for potential long-term colonization efforts on the Red Planet.

CONCLUSION

The success of this experiment will ensure continued growth of the human population, which has been fueled by agriculture during the comparatively recent development of the human race. A greenhouse is needed to create an artificial Earth-like habitat, which can only be accomplished and maintained when we are aware of the environment in which it will reside. It will be a true test to grow plants on an alien planet.Growing green on Mars presents significant challenges but also holds great potential. While Mars has a harsh environment with thin atmosphere, extreme temperatures, and high radiation levels, it is still possible to cultivate plants with the right technology and adaptations.Key considerations for growing green on Mars include:

1) **Atmospheric Conditions:**The thin atmosphere on Mars poses challenges for plant growth, as it provides less protection from radiation and has lower air pressure. However, with controlled environments like greenhouses or underground habitats, it is possible to create suitable conditions for plant growth, including adjusting temperature, humidity, and atmospheric composition.

2) **Soil Composition:**Martian soil, known as regolith, differs from Earth's soil. It contains perchlorates and lacks essential nutrients. However, research has shown that certain plant species can grow in simulated Martian regolith when supplemented with necessary nutrients. Future missions could also explore techniques such as hydroponics or aeroponics to bypass the challenges of Martian soil altogether.

3) **Radiation Protection:**Mars has higher levels of radiation due to its thin atmosphere and the absence of a protective magnetosphere. To protect plants, shielding can be provided through constructing habitats with thick walls, using radiation-absorbing materials, or even utilizing underground or subterranean farming techniques.

4) **Water Resources:**Mars has limited accessible water resources, and liquid water is crucial for plant growth. Future missions may explore techniques like extracting water from Martian ice or utilizing recycling systems to maximize water efficiency. Alternatively, plants could be genetically modified or engineered to require less water.

5) **Energy Sources:**Growing plants on Mars requires a sustainable energy source. Solar power is a viable option, as Mars receives ample sunlight. However, dust storms and the planet's distance from the Sun can pose challenges. Alternative energy sources, such as nuclear power or advanced energy storage systems, could provide reliable energy for long-duration missions.

In conclusion, while growing green on Mars is a formidable undertaking, advancements in technology and research can overcome many of the challenges. Successful cultivation of plants on Mars would have significant benefits, including providing food, producing oxygen, and potentially facilitating the establishment of sustainable human settlements. Continued scientific exploration and innovation will be crucial in making this vision a reality.

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