The Advancement of Mars Colonization Through Agricultural Development

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Abstract

A theoretical scheme to settle Mars was developed from the experimental results of a greenhouse prototype meant to mimic the growth of mung beans on Mars under Earth atmospheric conditions. Two systems were employed to simulate this environment: A soil-based system and hydroponic system. The first system had soils analogous to those on Mars which included synthetic regolith and Atacama Desert soil, along with potting soil mix as the control. The second system had a hydroponic setup with basalt rock as the medium for plant growth. From the soil-based and hydroponic systems, only the Atacama Desert samples and the basalt rock showed signs of mung bean growth. Basalt rock outperformed the desert soil with plants showing a statistically higher p value for stem length ($p < 1.59E-41$). To build a theoretical hydroponic space garden to sustain an Earth-independent colony the resources needed will be: food from the vegetation grown, water from Mars and from chemical processes, in addition to Mars's atmospheric gases such as oxygen, carbon dioxide, and nitrogen. Other resources that will also be gathered include hydrogen form the biomimicry of photosynthesis and perchlorates from the regolith of Mars. These resources will be used to produce fuels for the systems in the colony, maintain an adequate atmosphere for the vegetation, and as life support for the inhabitants of Mars.

Keywords: Space agriculture, colonizing Mars, Mars's agricultural development

I. Introduction/Background

The colonization and advancement of a sustainable population on Mars is paramount due to the degradation of Earth's environmental conditions, recurring severe weather events, and political interest. These events have encouraged governments and other agencies to explore the construction of Earth-independent colonies. Such a colony is defined as 25 people having plentiful sustainable resources that is unsupplemented by Earth after initial colonization. On Mars there are many challenges including: extreme temperatures; high radiation levels due to a lack of a global magnetic field and a thinner atmosphere; perchlorates in the soil, high concentrations of carbon dioxide, and constant sandstorms that make it inhospitable.[1,2] For an optimal colonization of Mars, an environmentally controlled space garden would need to be established to effectively grow vegetation in this harsh environment. This system will be successful with sufficient power production and autonomy to fulfill the requirements for the maintenance, extraction, refinement, and storage through adequate systems for the analysis, communication, and data archival of information.

Possible sources of power include nuclear, solar, chemical and wind. Of the four sources, only nuclear and chemical power are sufficient to sustain the space garden, since there are limitations for both solar and wind Energy that cannot be overcome.[1] The nuclear and chemical power sources will be employed together to manage their limitations. For the nuclear power, the Isotope decays and produces radioactive waste that must be disposed of.[3] For chemical energy, only a limited amount of fuel can be produced and refined, and it has byproducts that could potentially change the atmosphere of Mars over an extended period. Due to imminent fluctuations on power production, storage in the form of batteries will be included as a backup.[4]

The biological vegetation growth environment on Earth offers the essential resources that must be replicated to maintain a colony on Mars, along with having well understood biological mechanisms and byproducts.[5,6] Plants are renewable and can produce food and oxygen. Plants are also easy to transport through space, since seeds would be a fraction of the total food weight on each mission. A trip to Mars would last approximately 3 years and would average 11,000 kilograms of food for a four-man crew.[7,8] Another advantage to vegetation growth on Mars is that shuttle materials could be employed as vegetation housing during the settlement.[8] However, vegetation growth has disadvantages that must be managed or eliminated during the initial colonization. Accounted for are the fluctuating rates of return on the production of food, the gradual loss of yield, possible soil erosion, and decay of vegetation due to overuse during settlement.[5,6] The vegetation specimens were chosen by their growth rates, high yields of essential resources, and vegetation requirements along with the dietary guidelines of a vegan diet.[5]

In addition to plants, other essential resources from the Mars environment and chemical processes will be extracted and include carbon dioxide, water, perchlorates, hydrogen, nitrogen, methane, and other fuels. All these resources are essential to the eventual habitation of Mars. These resources are important since oxygen and water are necessary for human survival, food replenishment is key in maintaining a healthy diet, carbon dioxide and nitrogen derivatives are components of the vegetation growth cycle in addition to the Sabatier reaction, methane powers engines along with managing the garden's atmosphere, perchlorates are a hazard to humans and are oxygen rich, and hydrogen is one of the main components for most of the chemical mechanisms used in the colony and cannot be easily replenished.[6-12]

The initial transport of materials from Earth to Mars should be a collaborative effort to minimize the cost and keep funding constant. For this theoretical scheme to become a reality, well-recognized entities, such as: NASA, SpaceX, Titus Steel, Lockheed Martin, Farmbot, FCC, ACS, Sparkfun, Adafruit, and Boeing will have to cooperate. As such, communications to transmit the progress of the space garden will be an essential part of the project.

II. Methodology/Approach

A. Theoretical Studies

A. 1. Initial Colonization Studies

A. 1. 1. Geological Studies

The geological objective of this project was to structure a system to accumulate and consume Martian resources for the sustenance of an Earth-independent colony. The thin atmosphere, high radiation, and foreign agents in the soil and water have endangered several avenues for vegetation growth on Mars.[13] For this reason, a geological intervention was considered to design a sustainable growth environment focused on water, soil, and/or growing medium to produce a better prospect of plant growth. On Earth, there are constraints on growing vegetation in soils like those on Mars, so consideration on soil compositions were accounted for comparison to Mars regolith.[14] Through this study, geological samples on Earth, analogous to those on Mars, were used to develop a favorable growth environment. A prototype was constructed to test the experimental variables and the results were applied to improve the theoretical design. This will cut the cost of transportation of growing mediums from Earth to Mars and successfully producing food and biofuels for the colony.

Through these geological studies it was found that there are three options to produce a successful harvest. First, “In Situ Soil” is described as deceptively simple, since it yields good soil with no pre-treatments, but it is a scarce on Mars. Its demand for time spent on the prospect is anticipated to contest with the amount of good soil found, so it can only account for 5% of the space garden. Second, is the more abundant “Altered Soil” is differentiated by perchlorates and other compounds within the soil. With “Altered Soil,” there is a need to extract these compounds to produce good soil, which will cost more energy and resources than “In Situ Soil.” This selection is not optimal because of its improbable success, so it will only account for 10 % of the space garden. Third, is to use a basalt rock growth medium in a hydroponic system. This is more efficient than the previous alternative and demonstrates a philosophy of renewability by way of its water recycling. The cost of energy and resources for this system is greater than the previous two but has a higher probability of success. As a result, it will account for 85% of the space garden.

In the “In Situ Soil” case, identification of medium-grained size and non-toxic soil areas were considered. The presence of chlorine and the detection of perchlorates by the Phoenix and Curiosity landing sites supports the hypothesis that such foreign agents are distributed globally on the regolith of Mars.[15] The soil composition varies throughout these sites, so it is plausible for good “In Situ Soil” to be found, but the probability of finding these raw materials near the space garden is low. The location of these rare areas need to be close to the colony for optimal use of “In Situ Soil.”

With “Altered Soil,” removing soil contaminants, such as perchlorates, requires a complex system with considerable energy dependency. To begin, mining or washing the soil requires a substantial amount of water and pressure to continue the extraction of perchlorates. Alternatively, it was found that adding silica to the composition of the regolith or finding silica-rich soil, like in the Gusev Crater, will yield a higher plant growth. Another option to achieve the right composition a less clay-rich soil must be supplemented with more silica, which emphasizes the issue of isolating silica.

For the “basalt rock hydroponic system,” a soilless system will be considered as the growing medium for the vegetation environment. Soil is not the best option for hydroponics, since it would contaminate the water. Crushed basalt rock, which is found on Mars, can be considered for this application, because the rock will not breakdown easily. The system’s extraction, transport, and water consumption are also challenges that need to be examined. Most of the In-Situ water will be trapped in frozen deposits, so the purification system will include treatment for frozen water.[16]

A. 1. 2. Theoretical Execution of Geological Studies

“In Situ Soil” will require the detection of materials through a vast geological search. As such, an aircraft will be implemented to accomplish this task. (Figure 12 in the appendix) Excavation and transportation of useful materials will be needed to obtain good soil and return it to headquarters. Here, the use of heavy-duty mining trucks will be needed. For “Altered Soil,” the system will require: a mining station which consists of a conveyor belt, water purification line, pressurized water system, perchlorate detection system, excavation machinery, relative distance transport, and compartmentalization line. Basalt rock can be scooped and transported for crushing like “In Situ Soil.” The crushing requires a “heavy-duty jaw crusher” which is a machine that pulverizes the rock into smaller rock grain-sizes. Basalt rock is the appropriate density for most vegetation mediums because it holds stems upright. The containers in the hydroponic system can hold nutrient rich water and circulate it through different pumps. (Figures 13 and 14 in appendix) Essentially, the energy and resources spent by both the “In Situ Soil” and “Altered Soil” will be used toward the whole “basalt rock hydroponic system,” but will produce a better chance for colonization.

A. 2. Essential Resources Studies

A. 2. 1. Food

Vegan diets consist primarily of whole grains, meatless proteins, fruits, vegetables, and healthy fats. The general recommended daily servings from each food group are as follows: 5 to 7 servings of whole grains, at least 5 servings of meatless protein-rich foods, 3 to 4 servings of fruit, 6 to 8 servings of vegetables, and at least 2 servings of healthy fats.[17] Utilizing these nutritional guidelines, one food group from each category was selected for the inhabitant’s vegan diet. After the vegetative selection, a calculation for the quantity of food necessary to support 25 inhabitants of Mars was calculated from the daily servings recommendations for a vegan diet. (Appendix section A. 2.1.)

Grains are essential to a healthy diet, these should be whole grain products that have been fortified with additional nutrients such as iron, zinc, and vitamin B-12. These vitamins assist with red blood cell production in the body, protection from anemic conditions, and protection of body tissues from disease.[17] For these reasons, the grain selected was whole grain nutrient-fortified rice. Rice takes 4 to 5 months to reach full harvest maturity. On average, each acre plot will yield approximately 8,000 pounds of rice.[18] This will require a plot of at least 43,560 square feet with approximately 209 feet per side.[19] This is the lifecycle turnover rate and space needed for each batch of rice grown on Mars that must be tabulated to ensure adequate sustenance.

Rice, typically grown in a rice pond or rice “paddy,” already has the benefit of being grown in an aqueous environment. It is optimal for Mars growth since the amount of water lost through field seepage can be cut dramatically. A study from the United Arab Emirates has shown that rice can be grown in harsh desert environments with the use of hydroponics, where water used is strictly controlled and recycled.[20] Rice has many nutritional benefits because it is abundant in carbohydrates, which provide energy for the body. Additionally, rice lowers the chance of obesity, helps control blood pressure, and does not contain cholesterol, sodium, or harmful fats. The high fiber content, natural antioxidants, and phenolic compounds in the rice protects the body against certain cancers, Alzheimer’s Disease, and provides the body with anti-inflammatory properties. Niacin, Vitamin D, calcium, iron, thiamine, and riboflavin present in the rice provides fundamental nutrients essential for metabolic regulation, immune health, and general organ system functioning.[21]

The plant-based protein selected for the colonization mission will be soybeans. This meatless, plant-based protein is widely used in vegan diets as a high source of protein and a lactose alternative for many foods. Soybeans can be utilized for the manufacture of milk, tofu, tempeh, and any soy-based protein. A 100-gram serving of soybeans contains 173 kcal, 17 grams of protein, 1 gram of saturated fat, 10 grams of carbohydrates, and 6 grams of fiber.[22] Soybeans contain phytoestrogens, protein, and phytosterols. Phytoestrogens in soy beans, called soyaisoflavones, have been found to help block the effects of excess estrogen in the body. Phytosterols, like steroids and cholesterol hormones, inhibit the absorption of cholesterol by blocking absorption sites, lowering cholesterol. The protein in soybeans is processed differently than animal protein and will also lower the body’s cholesterol levels.[22] Replacement of all meat with soy-based protein would lower cholesterol intake by 123 milligrams per day and lower average saturated fat intake by 2.4 grams per day.[23] There could be a potential decrease in protein intake by approximately 8 grams per day. This decrease does not appear problematic, given that the average daily protein intake in the U.S. is nearly double the Dietary Reference Intake Level.[23]

Soybeans for shelling and fresh use are ready for harvest 45 to 65 days after sowing, and dry soybeans are ready for harvest after 100 days. They require approximately 2 to 4 inches of space between each plant and 24 to 30 inches apart between rows of growing plants. It is recommended that 4 to 8 soybean plants be grown per person per household to fulfill protein dietary requirements.[24] Growing soybeans hydroponically, compared to soil cultivation, promotes the accumulation of fats from 17.37 to 21.94 g/ 100 g dry matter, increases total dietary fiber from 21.67 to 28.46 g/100 g dry matter, and reduces isoflavones concentration from 17.04 to 7.66 mg/kg dry matter with no effect on protein concentration.[25]

The fruit chosen for the colonization mission will be blueberries. These contain a flavonoid called anthocyanin, which contributes to their numerous health benefits and antioxidant properties.[26] Blueberries contain iron, phosphorus, magnesium, calcium, manganese, zinc, and vitamin K.11. Consumption of the vitamins and minerals present in blueberries aids in maintaining the strength and elasticity of bones and joints, improves calcium absorption in bone, reduces blood pressure, helps manage diabetes, protects against heart disease, and improves mental health.[26] One cup of fresh blueberries contains 84 calories, 1.1 grams of protein, 0.49 grams of fat, 21.45 grams of carbohydrates, and 3.6 grams of dietary fiber.[26] This same serving provides 24% of daily recommended vitamin C, 5% of daily recommended vitamin B6, and 36% of daily recommended vitamin K.11. Another advantage of blueberries is that they can be grown hydroponically. The blueberry bushes should be spaced out 5 feet apart in a row, with at least 8 feet between rows for optimal growth.[27] It will take up to 1 to 2 years before blueberry bushes produce fruit. For this reason, bush transplantation is recommended as opposed to germination from seedlings. The hydroponic parameters for solution pH of blueberries should be kept between 4.5 to 5.8. The temperature should be kept between 22-24 °C, the blueberries should be exposed to 12-16 hours of daylight, and be kept at an optimal humidity range of 65%- 75%.[27]

The vegetable of choice for the colonization mission was green beans. Green beans are low in fat, contain no cholesterol, have a high fiber content, and satisfy some daily protein requirements.[28] This vegetable contains Vitamin A, C, K, B6, and folic acid which are sources of calcium silicon, iron, manganese, potassium, and copper.[28] Along with providing an abundance of nutrients, green beans also reduce heart disease due to their high levels of flavonoids, prevent colon cancer, control diabetes, boost immunity through antioxidants, and promote eye and bone health.[28] Grown hydroponically, beans germinate in less than two weeks, they should be planted approximately 2 to 4 inches apart, and should be grown in nutrient solution with a pH between 6.0 to 6.5. They should be suspended over either Perlite-Vermiculite blend of pebbles or expanded clay pebbles, because they are reusable, do not affect the growth pH, and are inexpensive. Regardless, they could also be grown on basalt rock. The temperature should be kept between 21- 27 °C and should be exposed to 12-13 hours of daylight. Beans grown hydroponically under these specific parameters will produce crops within 50 to 60 days.[29]

The healthy fats chosen for the colonization mission are peanuts. Peanuts have been associated with increased cognitive function, protection against Alzheimer's, protection against heart disease, lowered risk of mortality, and decreased development of chronic diseases. Peanuts are also rich in essential nutrients, such as fiber, protein, minerals, monounsaturated and polyunsaturated fatty acids, and antioxidants.[30] It is recommended that fluorescent, continuous lighting with 16°C and 28/22°C (day/night) temperatures be used, since they have been shown to produce the highest yields of peanuts. Dry weight yields of up to 207 g for peanuts have been produced in controlled environment hydroponic systems.[31]

A. 2. 2. Nitrogen

By composting all the organic wastes and vegetation scraps, a microorganism environment can be created for optimal conversion of atmospheric nitrogen into biologically accessible forms, like nitrates, through nitrogen fixation. Since composting is based on soil growth, a different technique must be applied to a hydroponic system. This technique will employ Compost Tea, which is a solution consisting of microorganisms and micronutrients transferred from the composting soil. First, this process starts by adding the compost into water along with a catalyst, which is a mixture of micronutrients that encourages microorganism growth. Both are added inside a sachet, where air is pumped for 24 hours. Then, the Compost Tea is ready to be added into the system. Using this technique, transportation of the synthetic fertilizers from Earth to Mars will not be needed.[32-34]

A. 2. 3. Ethanol

The largest fraction of ethanol fuel being produced currently is by the fermentation of carbon-based feedstocks.[35] However, for the Mars colonization model, this method of bio-ethanol synthesis will be difficult to perform. One of the goals of this project will be to successfully produce renewable ethanol as an alternative fuel without impacting the food supply. This new method of ethanol production uses water, carbon dioxide, and electricity delivered through a copper catalyst.[35] Researchers from Oak Ridge National labs have engineered an inexpensive, room-temperature catalyst for converting carbon dioxide into ethanol. The new catalyst is made of copper nanoparticles, electroplated onto a substrate of vapor-deposited, nitrogen-doped graphene nanospikes, situated on top of a slice of an n-type silicon semiconductor.[36] This system is plunged into a water bath, carbon dioxide gas is bubbled through the water, and then subjected to electrolysis.[36] The experiment yielded 120 proof ethanol at 63 percent.[36] The utilization of nanotechnology on common materials enables for the reduction of side reactions, and the predictability of the behavior of electrons in the presence of graphene is highly attributed to the effectiveness of this method.[36] This synthesis process will be good alternative if the methane fuel needs assistance maintaining the colony.

A. 2. 4. Hydrogen

The use of artificial inorganic leafs to mimic the photosynthetic process of plants is the ideal way to produce hydrogen. This will make all the processes to produce fuels, water, and oxygen, more productive. However, this technology is still under development and is not yet available for use outside of the research field. This technology recreates photosynthetic systems by using analogous molecular systems consisting of electron donors and acceptors to mimic light-driven charge separation. The foundation of this technology is the photocatalyst nanostructures that have been N-doped with TiO_2. These have shown promising preliminary results on the production of hydrogen. The challenge with the development of this technology, is that these nanostructures must be multifunctional since they must replicate the functions of chloroplast and other organelles to produce a process similar photosynthesis. If it is possible to use this system, colonizing Mars will be simpler. Since it is still under development, other processes such as water electrolysis will be the focus of this project.[37]

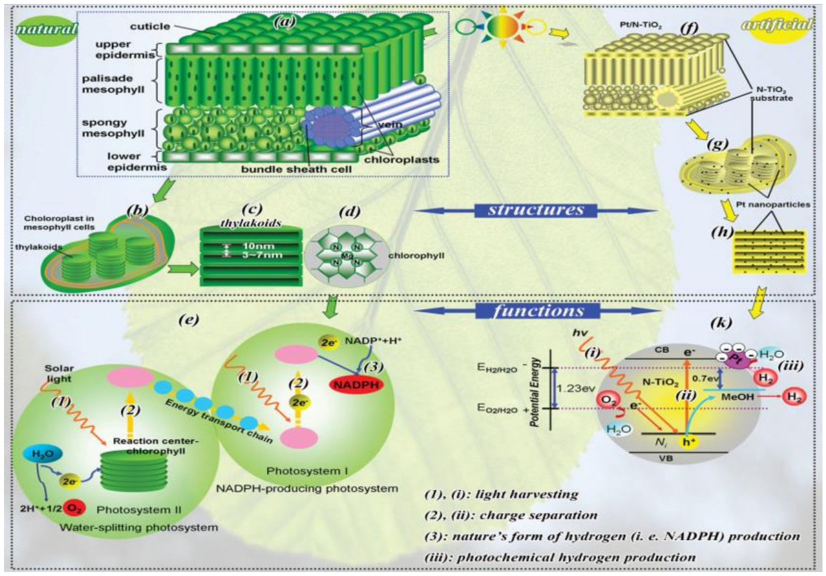

Figure 1. Shows both the natural and artificial systems of a leaf along with their structures and functions.[37]

A. 2. 5. Sabatier Reaction (water, methane, hydrogen, and oxygen)

When using a fuel cell, hydrogen and oxygen are electrolyzed to produce water and electricity. The water from this process can be used to produce oxygen and extra hydrogen through an electrolysis reaction. The oxygen gas produced can be used for breathing on Mars, while hydrogen can be combined with either the crew's expended or atmospheric carbon dioxide to produce more water. This is the basis of the Sabatier Reaction, which is the most concrete way for space colonist to receive the oxygen required for survival on Mars.[38,39]

$$2H_2 + O_2 \rightarrow 2H_2O + \text{electricity}$$

$$2H_2O + \text{electricity} \rightarrow 2H_2 + O_2$$

$$CO_2 + 4H_2 \rightarrow 2H_2O + CH_4$$

Figure 2. Shows the chemical mechanism of the Sabatier reaction to produce oxygen, water, hydrogen and methane for the sustenance of the space colony.[38,39]

The water produced by the Sabatier Reaction can be collected through centrifugation, condensation, or absorption. It can then be electrolyzed to form more hydrogen and oxygen. The hydrogen can be reused in fuel cells, while the oxygen will be employed to create a breathable atmosphere for the crew. The reaction also creates a methane byproduct, which will be used as the main fuel for the colony. Using the water produced from fuel cells, it should be possible to create a cycle which will require less water and hydrogen transportation from Earth and produce a sustainable environment for vegetation and humans.[38,39]

A. 2. 6. Perchlorates

When successfully extracted, perchlorates can be an optimal source of oxygen, since, these can be heated at temperatures around 300 °C to produce it. Once there is an efficient design to accumulate all the components to detect and extract perchlorates from the soil, there will be more oxygen for the colony's sustenance and cleaner soil and water for the space garden.

To successfully extract perchlorates from clay loam, loamy sand, and sandy soils, they will first need to air dry indoors. Perchlorates, like most salts, have lower freezing points than water, so a hydro-washing system can wash out the unwanted byproducts from the soils. Once dried, the soil must have a 1:1 ratio with water for it to be considered as a suitable extraction solvent. The filtered solvent is continually centrifuged for about 20-30 minutes before the filter is cleaned and reused. The water residue produced will have the dissolved perchlorates and can then be introduced to dichloromethane, an ion pairing agent. This pairing agent was chosen because of its high boiling point, which allows for the ions to remain while the water evaporates from the aqueous solution. This characteristic allows for the solution mixture to be evaporated, leaving a solid with the desired perchlorate byproducts in it. This solid salt will then be placed into a storage vessel.[40]

A. 3. Nuclear Studies/Power Production

A. 3. 1. Uranium Open-framework Analysis

Dr. Zehnder from Angelo State University and his collaborators at the Los Alamos National Laboratory (LANL) have synthesized a small number of uranium open-frameworks. It is essential to compare crystalline open frameworks of uranium to conventional fuels and perform density functional theory to identify their chemical characteristics. Metal organic frameworks (MOFs) have been shown to have the potential to solve some technical problems associated with f-block elements. Their ability to maintain their structural integrity upon removal of their ligands makes them suitable for catalysis, sensing, gas filtration/separation and gas storage, which makes them invaluable for on an Earth-independent colony.[41] Dr. Zehnder mentioned that the determination of structural integrity was inconclusive, which is why density functional theory calculations need to be performed to obtain further information about the MOFs. Previous studies conducted at the University of Houston-Downtown using this computational tool also highlights the importance of the theoretical data that can be obtained out of the synthesized uranium crystal. The purpose of having the uranium crystal MOF data is for comparison with the theoretical structure calculations. These can be used to determine the highest occupied molecular energy (HOMO), lowest unoccupied molecular energy (LUMO), molecular energy, stability, and polarity, which will be used to assess the molecular integrity of the MOFs.[42] The catalytic properties for these MOFs can be explored by applying density functional theory, with a basis set-specific uranium. This technique can be used to acquire the theoretical values for equilibrium geometries, molecular energies, dipole moments, IR spectra, and molecular orbital energies. (Figures 15-20 in the appendix)

A. 3. 2. Heated Air and Pressurization Systems Hot/Cold Air Compression and Rapid Exchange Chamber

The Multi-Mission Radioisotope Thermoelectric Generator (EMMRTG) component is needed for power, heat, and regulation of pressure for the space garden.[41] Traditional fuels, such as uranium oxide and plutonium oxide, are used to power the EMMRTG. Ideally, the atmospheric air will be used to pass through the heat source and go into the enclosed growth environment. The temperature on Mars averages around -80°C, so it needs to be heated to maintain the vegetation life.[1] This is a suitable alternative, but it has some drawbacks due to the dramatic difference of the carbon dioxide concentration between Mars and Earth. Another alternative that can be explored is to use combustion byproducts, carbon dioxide and water, to control the atmosphere of the vegetation without the use of an atmospheric environment.

A combination of these alternatives will be used to provide adequate ventilation, temperature, pressure, and safe storage of all the chemicals in tanks. The setup will consist of combustion chambers which will be connected to the growth environment, the atmosphere, and the EMMRTG.[41] The two airflows produced will have different temperatures which will power the thermoelectric generator. An important consideration about the EMMRTG involves the two components needed to manipulate temperature and pressure separately. One EMMRTG is insufficient because temperature and pressure are mutually dependent. If the temperature increases, the density of air coolant increases. This results in an increase of pressure, and vice versa. This dependency gives rise to another problem, which is the pressurization of the chemical storage tanks. To solve this problem, a turbo component can be used to compress the stored gases. The turbo component can also separate and select atmospheric or combustions air, depending on the need of the vegetation. Since this component only has room for two separate channels, it is important to determine where to connect them. Therefore, at least four turbo components are needed for the effective management of the growth environment. Depending on performance, more turbo chargers can be used for a more powerful EMMRTG, with the purpose of performing rapid air exchange and combustion for a large-scale growth environment.[44]

A. 3. 3. Thermal, Radiation Shielding (Borated paint) Isolation System Consisting of Separate Air Loops.

In this section, the safety aspects of the EMMRTG are assessed. Since the nuclear fuel is an alpha emitter, the sheets of metal do not have to be as thick as in traditional power plant reactors. The core of the EMMRTG will be made of mangalloy because of its high impact strength, abrasion resistant, and thermal conductivity. This material is stronger when there is excessive heat, which is a favorable property for safety.[43] One EMMRTG must be able to operate at elevated temperatures to counter the cold temperatures on Mars. If there are neutrons produced from the decay heat, borated paint will be included in the design because of its effectiveness at removing neutrons due to boron's binding energy.[45] Considering that the air channels will be isolated from each other, the air output and input will be designed so that the loop of the air channel connected to the EMMRTG does not mix with the vacuum of the air channel connected to the growing environment. The separation of the air channels is to prevent the uranium decay heat from being released. Additionally, if there is a rupture it will keep the growth environment safe.[44]

A. 4. System Engineering Studies

A. 4. 1. Electrical System

To power the system a few critical components are needed. While the EMMRTG will be a consistent source of constant power, components may draw different amounts of power throughout the mission. For this reason, batteries will store any extra energy to ensure all components have a sufficient power supply always. In addition to the EMMRTG, a power source, such as solar panels, could supply some additional energy to the system. Due to the fluctuation of power production with time of day and weather cycles, this source will not be the focus of the paper, but it has been added to the schematics nonetheless.

The power controller is a complicated component, as it must charge and discharge certain power rails depending on the status of the battery, EMMRTG, and other electrical components. A sufficiently sized heatsink will be needed to keep the system cool and radiate energy when the supplies are providing too much. The power regulators will be of varying voltages but will always provide enough current for the highest levels of power draw. Buck and buck/boost converters will be used for high efficiency power conversion, depending on the voltage required for each key component. Figure 3 shows a high-level overview of the power distribution system.

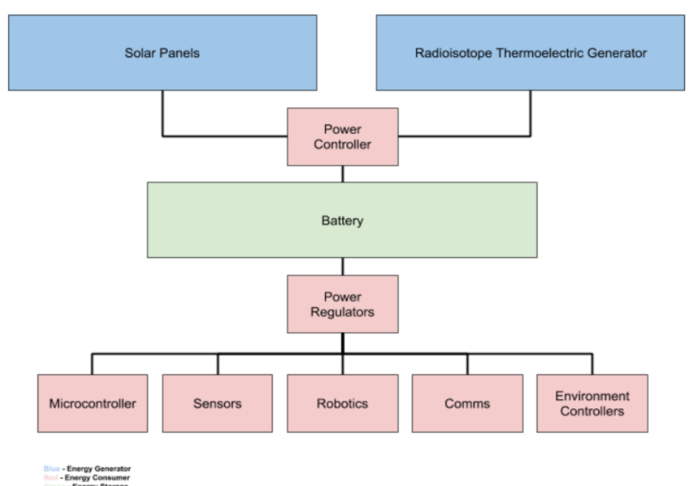

Figure 3. Shows the high-level layout of the power distribution system.

A. 4. 2. Communication System (Mars to Earth/ Earth to Mars)

For the downlink (path from Mars to Earth), the system will have two routes: one through a high gain antenna directly to Earth and one through the medium gain antenna via satellites orbiting Mars. The high gain antenna route will have a predictable link for a little less than half of the day, every day. This link will allow for information to be sent to Earth at most times in low quantities. The high gain antenna must be steerable, due to its tight beam width. While having this link is beneficial, maintaining the link will require a high gain antenna with high power draw and ultimately a low data rate. This will limit the usage to current state of the entire system. This may not be sufficient for substantial amounts of data from various instruments. To counteract this, a medium gain antenna will provide a link to satellites orbiting Mars, such as MRO and Mars Odyssey via X or Ka band.[46,47] This link will not require as much power and will be much higher data rate but will only be available for a few minutes at a time at different points of the Martian day. The system will have proper queues and buffers to deal with this. The medium gain antenna can be fixed-mount, as most orbital passes will be at lower elevation angles.

In addition to completing different links for varying mission needs, having both communications systems will make the mission reliable, robust, and redundant. In case of any software or hardware malfunctions, there should be more than one option for any system, which is no exception for communications. Without proper communication links, the mission will not be successful.

Like the Mars to Earth link, some redundancy will help alleviate any potential issues with one part of the communication link. Sending commands to the system will be important throughout the operation, so having a reliable link is necessary. The high gain antenna used for the downlink will also be used in one path on the uplink (Mars to Earth). This method will not allow for very high data rates but will have a somewhat reliable link for around half of the Martian day. Commands can be relatively low bandwidth, so the direct Mars link should suffice for most command activity. However, if larger data files need to be sent, such as software updates or schedule changes, a high bandwidth data link may be needed. For this reason, the system will also include a fixed low gain antenna that can receive data from satellites in Mars's orbit. This case is like the medium gain antenna, in that the link may be irregular and shorter, but allows for much larger quantities of information to be transferred. The radio included with the medium gain antenna will also have a receive capability in case of failure in the low gain antenna, but the ideal mission will use the medium gain antenna exclusively for transmission. Not only is this setup robust, it has also been demonstrated to work with the Mars Science Lab.[48]

As shown in Figure 4, there is a dedicated processor for every radio. This is just another way to decrease the chance of total communication failure, but it is not necessary. The prototype will not include this level of control, but, ideally, in a mission to Mars every radio would have a dedicated microprocessor which stores information to be sent/received in queues for the processor to handle. By separating these microcontrollers, the processor can prioritize mission software while pulling and adding to queues when necessary.

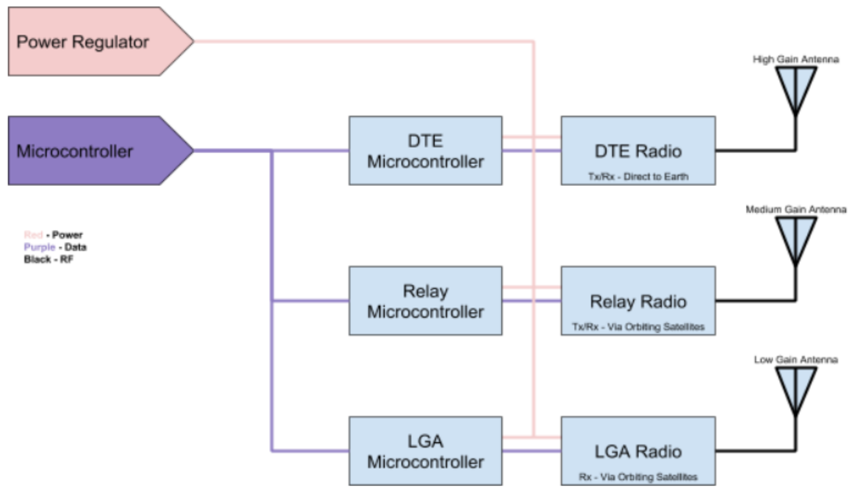

Figure 4. Shows a high-level overview of the communication systems.

A. 4. 3. Insulation

Aerogels will be placed on top of the radiation shielding to insulate and protect the growth environment from temperature and sand storms. Aerogels are high-surface-area porous solids that will be employed due to their light weight and low heat conduction to achieve optimal insulation in the Mars environment. Aerogels are made by creating a gel then extracting the solvent with supercritical fluid extraction. This leaves a very porous, low-density solid. Due to their porous nature, aerogels are the finest insulation materials available. Silica aerogels are good insulators as well but will flake apart because of the high winds and sand storms on Mars. For this reason, all-polymer aerogels should be used over their silica-based counterparts. They can be created as thin, flexible films and are 500 times stronger than silica-aerogels. These polymer aerogels can withstand temperatures of up to 400°C without degradation and can placed beneath heat-resistant ceramic fabric. These aerogels resist wear and tear due to moisture and maintain their flexibility. Their moisture resistance and their unparalleled insulative properties make all-polymer aerogels optimal for the space garden on Mars.[49,50]

A. 4. 4. Essential Gases and Fuel Storage

Currently, transportation of hydrogen to Mars is the only way to replenish it. The only approach that is considered viable while transporting hydrogen is to store it as a cryogenic liquid. The hydrogen is stored in small multi-layer insulation tank. This is done in smaller tanks, rather than larger ones, due to consideration of the packing density. While transporting the hydrogen, there is unavoidable boil-off loss that can range from 2-7% per month of traveling. This is a problem due to the 3-year travel time to Mars.[7] Liquid hydrogen must be stored at -252.78°C and must be carefully insulated from heat to minimize the boil-off loss. As hydrogen absorbs heat from its surroundings it expands, so venting is also necessary to avoid explosions.[51,52] Once the hydrogen reaches the surface of Mars, it will be even more difficult to store since multi-layer insulation tanks are ineffective in the Mars atmosphere. It is thought that the hydrogen can be immediately used in the Sabatier Reaction. This will bypass the need for storage on Mars, but there is little research data on the subject.[51] If water is readily available on Mars, it is possible that the Sabatier Reaction can be employed using either the crew's expended carbon dioxide or atmospheric carbon dioxide to produce hydrogen and oxygen. This is a potentially valuable way to create oxygen without the need for storing and transporting hydrogen. Though, even with the reaction, there is almost no way to avoid the need of transporting hydrogen from Earth in the near future.[53] As previously stated another alternative will be to use new technology based in biomimicry to produce this essential compound.

The most plausible way of storing oxygen is to convert it from the gas phase to the liquid phase and place it in cryo-tanks. The tube-in-tank method has been tested in terrestrial based demonstrations and shows that oxygen can be stored within a zero boil-off storage tank. This storage tank directs the refrigeration to the inside of the tank, which allows for the tubing to be in direct contact with the oxygen found inside the tank.[54]

Methane must be stored at a temperature of -161.6°C as a liquid.[55] Liquid methane can be stored in multilayer insulation tanks with a foam insulator. The insulator helps to reduce the amount of leakage over time due to heat. The tanks also include a passive thermodynamic vent system to safely remove the vaporized propellant. There could be a cryocooler included in these tanks to help to reduce heat leak and boil-off, but this would require extra energy and weight demands.[56]

Ethanol is stored in the liquid phase in cylindrical graphite composite tanks. The tank's pressure is regulated using a high-pressure gaseous helium pressurization system.[56] An advantage of using ethanol as a propellant is that it remains in the liquid phase over most of the Mars temperature ranges. Its melting point is between 97°C and -115°C.[57]

A. 4. 5. Watering System

The watering system will be designed based on the schematics used in previous experiments done by NASA, specifically, the Lunar Martian Greenhouse Project. In this project, the water was stored in a large container under the plants and pumped into an array of tubes that directly deliver the water to each one. The amount of water delivered was regulated through the size of the tube and operation time of the pump. The water drained through the pots was collected using a slanted collector and was recirculated back into the system. This system worked on the ideology of recyclability and can be modified to fit a hydroponic system. Thanks to its chemical properties storing water on Mars will not be a big challenge, but it will be important to supply tanks, with easy access for the inhabitants, that can handle the sand storms on Mars.[58]

A. 4. 6. Software/Hardware System

The technology that will be implemented on the space garden to achieve autonomy will be a Farmbot. The way Farmbot gains its autonomy is with the variety of sensors, tools, and software. This entire system is open source, so there are many resources available online for anyone to get started on planting their own farm and flexible programing for additional functionality. The Farmbot is built over a bed of land where vegetation will be planted. Setting up and running the Farmbot system is simple, as seen by its use in third world countries. For these reasons, setting up this system on Mars will be convenient, and it will continue to function regardless of the physical human interactions with the system. As such, this system is not only autonomous but can be operated remotely. Farmbot OS, the operating software for the Farmbot, will be preloaded on a Raspberry Pi microcomputer to run a belt system to control the X and Y axis around the vegetation bed. There are sensors to monitor temperature, humidity, and soil moisture throughout the system and on the robotic arm. There are also tools to break up the soil, plant seeds, water the plants, and to kill any weeds, which will be important for the autonomy of the system.[59]

III. Results/ Discussion

B. Discussion of Prototype

B. 1. Prototype Geological Studies

B. 1.1. Composition of Atacama Desert Samples

The Atacama Desert is registered as the driest place on Earth and It has been used previously in studies of Mars's geological characteristics. NASA has used samples from this desert for testing instruments for missions to the red planet. Isotopic studies indicate that natural perchlorates are produced on Earth's arid environments by the oxidation of chlorine species. The release of chlorine correlates with the release of chlorinated hydrocarbons (Figure 5), suggesting that an oxychloride compound, such as a chlorate or perchlorate, is the source of the oxygen and chlorinated volatiles. Perchlorate deposits in the Atacama are closest in abundance to the samples collected on the phoenix lander because of the similar atmospheric conditions. Perchlorates occur at Mars-like levels only in the Atacama Desert, where peak perchlorate concentrations reach 0.6 wt. % in veins of white-colored nitrate ore known as Caliche Blanco.[1] The samples from this experiment were collected near San Pedro, Chile, in a valley of salt, and are derived sediments from basalts from the Andes formations, in the Atacama Desert. The samples were collected and marked, naming the locality relative to the sample area. The samples were then prepared at University of Houston-Downtown for the growth of the vegetation of the prototype.

Figure 5. Shows the arid Atacama Desert which has analogous conditions and regolith to that of Mars.

B. 1.2. Composition of Synthetic Regolith Samples

Based on Alpha Particle X-ray Spectrometer (APXS) chemical analyses, the rocknest aeolian bedform is representative of global basaltic soil at Gale Crater. The inferred chemical composition of the amorphous component (Table 3 in the appendix) contains ~20% Fe_2O_3, suggesting that nanophase ferric oxide is present. Last, if MER-like levels of are present in rocknest soil, then the amorphous component must also be the carrier that is responsible for the reddish color of the soil. The absence of smectites is surprising because orbital spectral data suggests the presence of smectites in and around Gale Crater. This reveals that the soils observed during the first 90 sols at Gale crater follow a compositional trend between two major end members: a mafic component (cluster 1 or "mafic type"), and an alkali-, aluminum-, and silica-rich component (cluster 2 or "felsic type"). Opportunity has investigated in detail rocks on the rim of the Noachian Age Endeavour Crater, where orbital spectral reflectance signatures indicate the presence of -rich smectite. Compositional data for fractures in the layered rocks suggest formation of Al-rich smectites by aqueous leaching.

As a result, the synthetic soil composition was derived from scientific papers written from these Gale Crater rover missions. (Table 3 in the appendix) The synthetic composition ingredients were ordered and mixed without any further treatment following previous studies that made synthetic soil at the University of Houston Downtown. After the weight of individual components were calculated and measured, they were mixed together. The silica synthetic soil composition of the mixture was increased over every cycle to try and improve the growth of the vegetation. The trace element signature from the soils used in the prototype were made following these specs and were used to compare the actual data points on Mars regolith.

B. 1.3. Composition of Basalt Rock Samples

Rocknest (sand dune area) consists of both crystalline and x-ray amorphous components. The crystalline component is basalt, composed of plagioclase feldspar, forsterite olivine, and the pyroxenes: augite and pigeonite. All the minor phases are consistent with a basalt heritage, excluding anhydrite and hematite. The crystalline component of rocknest is chemically and mineralogically like that inferred for Martian basalts across the planet and many of the basalts found in Martian meteorites. To analogize the same basalts from that of Mars, basaltic-rock used in the experiment was collected in New Mexico. This basalt rock is analogous to the olivine-rich basalt rock found on Mars. The samples were brought back to the University of Houston-Downtown for prepping. The rocks were originally in large rock form, so crushing was needed to make the targeted medium-grained size. After this procedure there were multiple grain sizes, so there was a need to separate the consistency of the grain size by sifting the rocks in a 3-layer pan. The grain sizes consisted of .0197, .0394, and .0787 in. (.5, 1 and 2 mm sized grains, respectively). After a water wash, .0197 in. grain size was chosen to be the hydroponic medium because of its smaller size. (.0394 in.) Then this crushed basalt rock was implemented to a separate set of 40 samples to test the success of a hydroponic growth medium.

B. 1.4. Composition of Potting Mix Samples

The potting mix used was store-bought and used without any pretreatments. This was moisture control potting mix from “Miracle Grow.”

B. 2. Prototype Design

B. 2. 1. Prototype Structure

The structure of the greenhouse included a frame made of wood that extended 76 in. in length and 24 in. in width. On this frame, there were two sections, one for the electrical components and one for the metal housing. The metal housing was made of steel and plexiglass and had the measurements of 64 in. by 24 in. Inside the metal housing there were two levels that contained the soil system (top) and the hydroponic system (bottom). This housing also had two fans, for optimal circulation of air, placed near the bottom right and at the top left. (Figure 6)

Figure 6. Shows the structural components of the greenhouse prototype which included the soil and hydroponic systems along with all electrical components.

B. 2.2. Prototype Growth Cycles

For the duration of the project, a total of three cycles were performed. The experiment was devised to analyze the growth pattern of mung beans using soils analogous to those on Mars (synthetic regolith and Atacama Desert soil). To have an accurate baseline for the experiment, a control (potting soil) was used for comparison with the Mars soil samples. To increase the chances for growth and determine whether the transport of micronutrients was necessary for successful colonization, "Miracle Grow" was used for 10 out of the 20 cups of synthetic and desert soils and their performance was recorded. Each soil sample had 10 cups to increase the statistical points in the results, which made up a total of 50 cups for the soil system. Each set of soils was randomly assigned to avoid any growth inconsistency due to placement of the specimens inside the greenhouse. For all the growth cycles performed the placement of the specimens was repeated as shown in Figure 7.

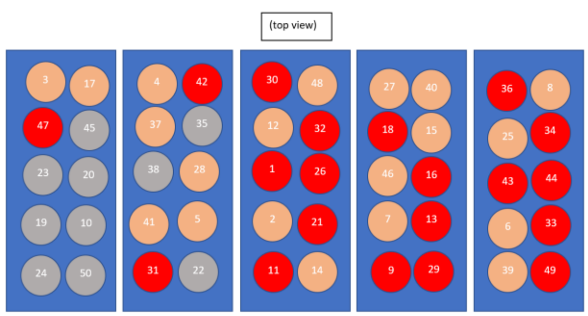

Figure 7. Shows the placement of each soil sample as they were laid out in the greenhouse with the colors distinguishing what type of soil they belong to. (**synthetic soil**, **Atacama soil**, **potting mix**)

For the first cycle, 10 specimens were used in each cup, the watering system was set to irrigate once a day, and the lights were set on a 16-hour daylight schedule. The sprouts were collected after 20 days and their stem length was measured after drying. In the second growth cycle, 5 specimens were used in each cup to encourage specimen growth and the watering system was set to irrigate once a day while the lights were scheduled the same way. The procedure followed in recording the growth patterns and the time frame of the growth cycle, were the same. The implementation of the hydroponic growth system was also included in this growth cycle, to test the effectiveness of the mung bean growth in hydroponic conditions. The nutrients necessary for the specimens were added into the water reservoir after planting the mung beans. The plants were grown in 40 cups that had basalt rock and were semi-submerged in water. The second growth cycle was done under the same experimental conditions as the first cycle. For the third and last cycle, the only parameters changed were the light source height due to the difference in light intensity across the system and the ratio of silica in the synthetic soil.

B. 2.3. Prototype Soil System

The soil system was the first to be integrated in the prototype and was held by a 64-in., 2-part structure. This structure was adjustable in height and angle to achieve optimal water flow. A plastic container was tailored to fit the platform and was used as the base to hold the mung bean specimens. On this horizontal platform 50 holes (1.75’’) were drilled to the place plastic cups. The set up was organized in 10 columns and 5 rows. 2 fluid ounce cups were used to hold the specimens and had a fitted funnel at the bottom. 0.0394 inch-sized basalt rocks were placed in the funnel to prevent soil from being washed out of the cup during daily watering. The sprinkler system was positioned at the top of each of the soil samples, where it ran water through the cups and onto the tray placed below the samples. The tray had an angle of 15 degrees from the horizontal, ensuring optimal run off. After the water was collected at the bottom of the tray, a tube was cut in half and taped to the edge to pool the water towards the beaker. As a result, the water naturally ran down the direction of the entrance of the greenhouse and got collected in a 2 Liter beaker which was manually drained after two weeks.

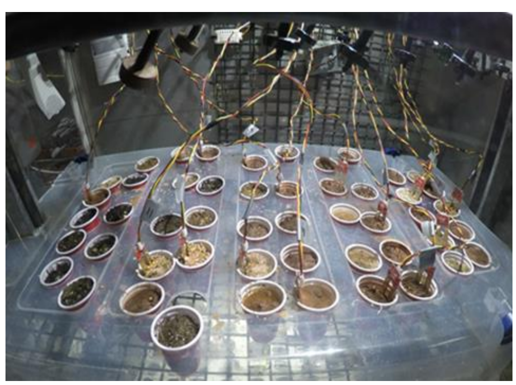

Figure 8. Shows the soil experiment platform inside the prototype.

Table 1. Shows the different soil compositions tested in the prototype.

Soil Types
Atacama Desert soil samples with no additives (San Pedro, Chile)
Atacama Desert soil samples with no additives (San Pedro, Chile)
Synthetic Soil with no additives (UHD lab; Houston, TX)
Synthetic Soil with nutrients (NPK; “Miracle Grow”)
Nutrient rich Potting Mix with no additives
Nutrient rich Potting Mix with nutrients (NPK; “Miracle Grow”)
Crushed Basalt rock in nutrient rich hydroponics (Capulin, New Mexico)

B. 2. 4. Prototype Hydroponic System

The hydroponics system was implemented after the soil system and was constructed in a 2-way chamber (one vertically above the other). Combined, the chambers had a total of 51 liters of water. The lower chamber (STERILITE Storage Tote, 14 Gallon) contained air stones and a water pump that circulated the nutrients placed in the water. The upper chamber (Sterilite® Clear Plastic with White Lid, 7 Gallon) had a smaller-sized container with a flat piece of plastic that had 50 holes in it (10 columns, 5 rows). These holes in the platform contain the cups which sat well inside and above the water in the container. The upper level had a hole, that drained the water into the lower chamber. The same plastic cups from the soil experiments were used, which were drilled with holes on the bottom and sides to help water flow and roots spread. Nutrients were added to the lower chamber and were circulated throughout the system.

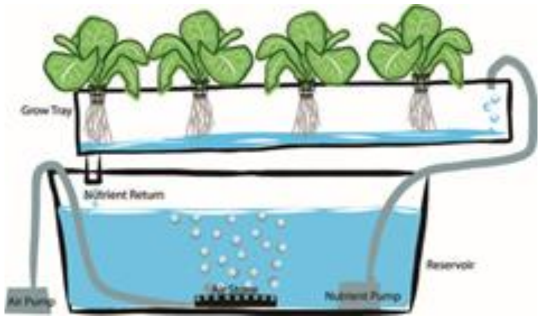

Figure 9. Shows the 2-way chamber system design that was implemented in the greenhouse prototype.

Figure 10. Shows the hydroponic platform inside of the greenhouse prototype.

B. 3. Prototype Electrical Components

The greenhouse needed an automated system to water and light the vegetation, as it would on Mars. The timing for each component (water and light) were set individually to simulate typical day and night times for the Mars's habituation. (Figure 21 in the appendix) The watering timer required a time-sensitive dial which allowed water to be poured from the pump for no more than 5 seconds. This was accomplished by setting a regular hour-timer to a more sensitive second-timer. Only by this method, it was possible to keep a constant watering schedule. The lighting consisted of 2 high-powered LEDs which provided 1,351 lumens in a neutral 4,000K CCT, with a 50,000-hour LED life, which had a rugged cast aluminum housing provide and 74 lumens per watt. (Figure 22 in the appendix)

B. 4. Prototype Computational Components

Data can be used to determine if there is a problem with the vegetation or its environment. The potential problems that could rise are the lack of nutrition, moisture, Carbon dioxide, or lighting. Measuring all these is expensive, so only moisture, temperature and lighting were measured. An array of 16 moisture sensors were used to detect water levels. Initially, only 4 different soils were measured, which included the desert samples with "Miracle Grow", and without "Miracle Grow", in addition to the synthetic soil samples with and without "Miracle

Grow". The potting mix soil was not measured since it's not available on Mars and because it is the controlled variable. Measuring the temperature and humidity of the environment gives insight into why some plants don't grow and maintain accurate readings on temperature fluctuations. Later in the experiment, photoresistors were used to measure the amount of light that the mung beans received, in both soil and hydroponic systems. These sensors turned out to be inaccurate, so they were not included in the results of the project.

To collect massive amounts of data, a microcontroller that can read multiple Analog inputs had to be used. Only few microcontrollers can handle this number of sensors, so an Arduino Mega was used since there is extensive documentation available. The 16 moisture sensors were connected to the 16 analog inputs and were powered using 16 of the 54 input/output (I/O) pins. Another digital pin was used to collect the temperature and humidity, while 4 other digital pins were used to read the photoresistor readings. The data was stored temporarily as a variable and was sent through a serial to the user's computer. To analyze the data, it had to be stored. The Raspberry Pi was used for this specific purpose, since it is a computer that allows multiple Input/output devices, such as a keyboard, mouse, USB and display. For this project, the Pi's job was to run the Arduino's Integrated Development Environment (IDE), read the data from the serial port (USB), and collect the data in a spreadsheet as a comma-separated value(.csv).

C. Results of growth experiment

C. 1. Preliminary Findings for the Prototype

First, the hydroponic environment showed effective growth for an average of 4 specimens for each cup with an average stem length of 6.91 inches between all growth cycles. Secondly, soil samples did not show the same growth patterns and were considered unsuccessful throughout the cycles. Within the soil samples, there were different soil types, as previously mentioned and is shown in Table 1. As expected, the control (potting soil samples) grew an average of 4 specimens with an average stem length 4.29 between all growth cycles. Poor growth patterns of the desert and synthetic samples were observed, especially during the first and second cycle. This performance can be attributed to the placement of the light during the first two growing cycles, which was placed higher than the hydroponic system light. However, there was an added ratio of silica between the cycle. This could have contributed to the growth of the Atacama and synthetic soil, so this should be considered as a factor. For verification of this analysis, a fourth cycle is currently being conducted with the soil system's light fixed at the same distance as the hydroponic light. Moreover, it was determined that while light intensity may have influenced the soil system, it was not dramatic enough to cause a change in the hydroponic result. However, when further carrying out the hydroponic system process, it should be noted that light placement and intensity is critical for mature growth, since the specimens furthest from the light source show less growth than those closest to the light source. Another issue that might have caused the poor growth of the desert and synthetic sample was the use of "Miracle Grow" which was determined to be incompatible with the soil growing system. This was observed by the buildup of "Miracle Grow" residue on top of the soil samples and its presence inside the collection beaker. (Figure 11)

Figure 11. Shows the water collection beaker with "Miracle Grow" (right) in addition to the precipitate formation on the soil samples (middle and left)

C. 2. Prototype Soil System Results

It was recorded that the for the first growth cycle the clay rich synthetic soil had no mung bean growth. This failure was observed through the poor handling of water by the soil. During the first 10 days of the cycle, the synthetic soil hardened, and the specimens could not grow. To fix this problem, the second run was modified by using less seeds to avoid overcrowding in the cups. For the second run, 20% more SiO_2 was added to produce a silica-rich felsic type soil (Cluster 2). The composition in this case was set to 66.1% Silica for the synthetic sample. While this did show less signs of precipitate formation and hardening in the sample size, the success was substantially lower. The increase in SiO_2 was repeated for the third cycle to produce an 86.1% Silica composition of Synthetic soil, which showed more mung bean growth but at very low specimen numbers.

C. 3. Prototype Hydroponic System Results

For the hydroponics system, maintaining the water level between chambers was essential, since the water level in the upper chamber shifted from being too high to too low. The fluctuations were not catastrophic but did remove some consistency in the experiment. It should be noted that a regulation knob was being used to manage the water flow between the tubes where the water was being pumped from. In future experiments, this manual knob should be fixed to be electronically automated to give get a constant regulation of water level. Regardless of these small issues, as previously stated, the hydroponic system outperformed the soil system.

C. 3. Prototype Limitations

The first limitation encountered during the experiment was the lack of variance in light intensity of the prototype, which did not yield an environment comparable to the ideal indoor-growth environment targeted. Moreover, a restricted growing season for the mung beans, along with a limited amount of growth cycles, did not allow for further studies to improve the performance of the soils to be explored. The wait time on prototype components was also an issue because the electrical components were mounted at specific times during the experiment, and component additions to original prototype were necessary. These additions were tedious to implement without altering delicate components within the structure. Finally, adding components and changing growth variables increased the variability of the final experimental results.

IV. Conclusion/Recommendations

D. 1. Project Conclusion

Future work on the overall greenhouse prototype will be done to ensure of the data, accuracy, and repeatability. If possible, additional cycles will be performed to acquire the optimal parameters for the success of the theoretical space garden. Concerning the theoretical design, deeper studies in the areas covered on this paper must be preformed to increase the possibilities of the Mars scheme developed here to be used for the real colonization of Mars. From all the findings, a general scheme was successfully deduced, but planning for the initial colonization needs to be done. This this initial stage will determine the best plan to achieve the eventual construction of the theoretical space garden and development of an Earth-independent colony on Mars

D. 2. Project Reflection

Michael Bustamante: I learned that it was quite a challenge to lead a team through this whole project. It was hard to plan everything and communicate my ideas effectively to the team. From this experience I learned what it would be like to propose a research project to a professional company. Many of the experiences I had through this project were new and will impact me professionally and personally. I learned a lot about writing essays and how to condense information effectively.

Andrew Cline: This project has taught me a great deal about time management. There were times during this project that I had other stuff to do, but I found the time to work on the project and other homework. It probably helped that I had a leader that kept pushing for me to get it done. Hopefully I can continue to be strongly lead in the right direction for whatever I decide to do outside of school.

Julio Enriquez: Being a member of this UHD USDC Team has been an honor because of its continual community impact. When I present ideas to students, professors, or advisors, there is an important sense of open mindedness. The studies I focused on were the experiments on soil-medium composition which favored the most optimal plant growth. The science we are doing here at the university are collectively understood as we continue to integrate different disciplines in the natural sciences.

Ignasio Hernandez: The opportunity to be a part of the UHD USDC Team was an amazing experience as an undergrad. Being in this team helped show me just how creative a team can be in the process of building a greenhouse with the potential to go to mars. As I was working on the computational components of this project, I developed a deeper understanding in raspberry pi, how to add sensors to it, learned how to solder, and troubleshooting. I would like to thank Michael and Moises for helping me throughout this process. The leadership they gave in my position gives me confidence in performing high for this competition.

Skylar Hoffert: Personally, I have always wanted to work on a project that would build a path for sending humans to Mars. Being able to work on this team has been a real dream come true! In my studies, I have always focused on the engineering side of things, but my interests have always extended further than that. As the others would build up the main portion of the project (the science), I was able to take in a different sort of information -- this has been a fantastic takeaway for me. Our work on this project truly motivates me to explore Mars and makes me excited for the future!

Trung Le: I'm glad to be a part of a talented team under a great leadership. Michael has been instrumental in our cooperative effort to get the proposal moving smoothly through the various stages. I was given the task of figuring out the biological needs of plants and their optimal growth environment. Along the way, I learned many new things about Mars and our own Earth.

Moises Nunez: This project has taught me many things, one being the importance of teamwork. The longest project I had worked on prior to this design challenge was 2 months and this project was over a semester long. Having my friends help me wire and get the electronics up and running was great. They learned how to solder, and I learned more about the vegetation cycles and how the environment plays a key role in plant growth. I want to thank Ms. Gad for providing majority of the sensors and microcontrollers and helping our team go above and beyond.

Jordyn Stanek: The opportunity to be a part of the UHD USDC Team as an undergraduate was a most rewarding experience. I was incredibly grateful to present how the nutritional benefits that an all vegetarian diet could benefit the body and the environment being colonized. I was also grateful for the opportunity to work with individuals from such different academic backgrounds and to meet like-minded students who are as dedicated to their academics as I am. I learned that I am capable of being able to balance my course workload, while also completing a project and that I can write out of my comfort zone.

Aaron Torres: I am proud of being part of this team for the NASA USDC. Meeting new people has developed my networking skills and has given me exposure to researchers who are from diverse degree backgrounds like computer scientist, chemist and geologist. I was able to use my research expertise to study about decay heat, which could have the potential to be used to heat a Martian artificial atmosphere. I have learned a lot about the applications of nuclear power in space exploration which has gotten me out of my LWR comfort zone. Thanks to Dr. Benavides & Dr. Zehnder, I was able to study the uranium open-framework models.

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Appendix

A. 1. Geological studies

Figure 12. Shows the aerial prospect of the aircraft searching for water deposits on Mars.

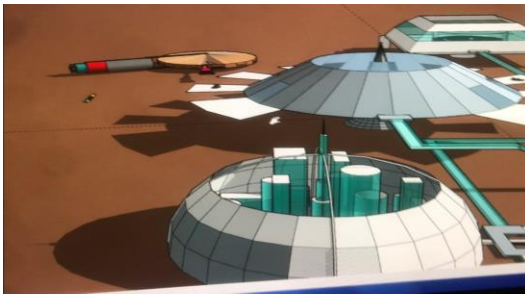

Figure 13. Shows the water purification line transporting melted water through several treatment stages.

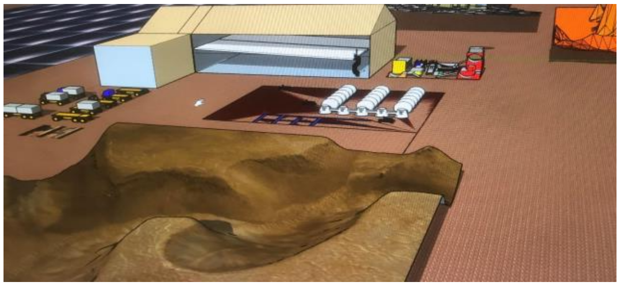

Figure 14. Shows Theoretical greenhouse environment and ground transportation next to it.

A. 2. 1. Food

Daily Serving portions:

7 servings whole grain – 1 serving portion: 1 cup to ½ cup = 7 to 3.5 cups per person daily
5 servings plant-based protein – 1 serving portion: 3 ounces = 15 ounces per person daily
4 serving fruit – 1 serving portion: ½ cup = 2 cups fruit per person daily
8 servings of vegetables – 1 serving portion: ½ cup = 4 cups of vegetables per person daily
2 Servings of healthy fat – 1 serving portion: 1.5 ounces nuts per person per day

Daily Serving portions for 25 people a day:

Whole grain: 3.5 cups (25) = 87.5 cups
Plant based protein: 15 ounces (25) = 375 ounces
Fruit: 2 cups (25) = 50 cups
Vegetables: 4 cups (25) = 100 cups
Healthy fat: 1.5 ounces (25) = 37.5 ounces

How much needed for 10 years:

Whole grain: 87.5 cups (3650 days) = 319,375 cups = 2,555,000 ounces = 159,688 pounds
Plant based protein: 375 ounces (3650 days) = 1,368,750 ounces = 85,547 pounds
Fruit: 50 cups (3650 days) = 182,500 cups = 1,460,000 ounces = 91,250 pounds
Vegetables: 100 cups (3650 days) = 365,000 cups = 2,920,000 ounces = 182,500 pounds
Healthy fat: 37.5 ounces (3650 days) = 136,875 ounces = 8,555 pounds

A. 4 Power production/ Nuclear Power Studies

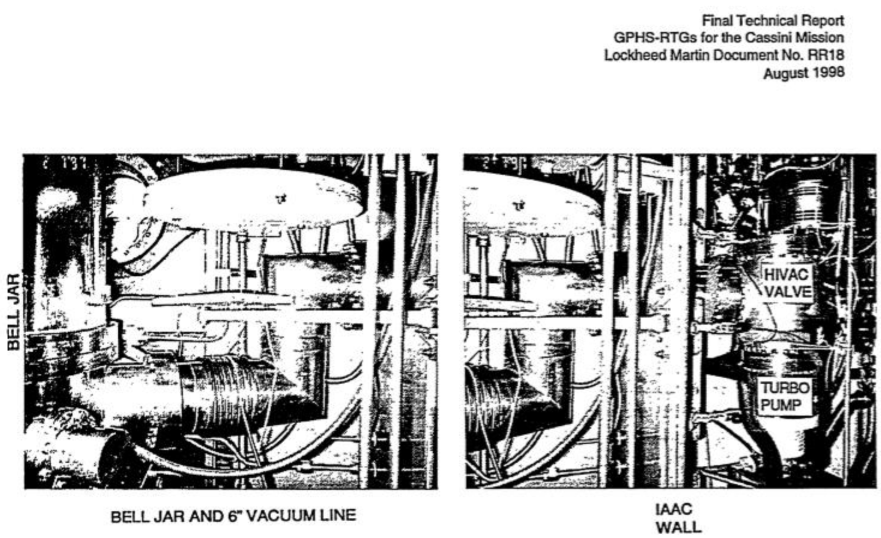

Figure 15. According to the 1988 Lockheed Martin GPHS-RTG for the Cassini Mission, this component lacked artificial carbon monoxide pressurization. Ideally, this design along with a combustion chamber can account for the carbon monoxide by replacing it with carbon dioxide to control pressure.[41]

Table 1. According to the 1988 Lockheed Martin GPHS-RTG for the Cassini Mission, list the data obtained from 4 different rtg models with a temperature range of 262 Degrees Celsius.[41]

	F-2 RTG	F-5 RTG	F-6 RTG	F-7 RTG
Date	2/18/96	12/16/84	11/21/96	9/10/96
Hour	1800	1400	1000	1200
Heat Input, watts	4435	4458.6	4437	4435
Power Output, watts				
As Measured	295.9	305.5	298.2	297.9
Corrected to Pins	297.8	307.6	300.2	299.9
Normalized to 4410W Input *	294.8	301.8	295.8	296.9
Load Voltage, volts	30.034	30.070	30.144	30.031
Open Circuit Voltage, volts	51.751	51.94	51.873	52.305
Current, amps	9.851	10.158	9.891	9.921
Internal Resistance, ohms	2.205	2.152	2.197	2.245
Average RTD Temperature, °C	262.5	262.6	261.2	261.4
Insulation Resistance, k-ohms				
Thermopile to Case (2 minute)	2.7	6.42	4.12	2.49
Chamber Pressure, torr	4×10^{-5}	2.8×10^{-6}	1.1×10^{-5}	8.2×10^{-6}
Average Sink Temperature, °C	68.3	68.8	57.8	61.3
CO Partial Pressure, torr	4×10^{-6}	2.3×10^{-8}	3.3×10^{-6}	1.1×10^{-6}

Table 2. Shows the data obtained by Dr. Zhender of the 5 uranium crystals which are being studied; This table contains information about the bond length, angles, system, etc.[41]

Table 1. Crystal Data and Summary of Data Collection and Refinement for Compounds 1−5

formula	$[[UO_2](TP)(H_2O)_2]\cdot 2THF$ (1)	$[[UO_2](TPNH_2)(H_2O)_2]\cdot 2H_2O$ (2)	$Na_2[[UO_2]_2(TP)_3]\cdot 9H_2O$ (3)	$Na_2[[UO_2]_2(Glut)_3]\cdot 8H_2O$ (4)	$U_6(NO_3)_4(Glut)_4(O)_4(OH)_4(H_2O)_6\cdot 12H_2O$ (5)
fw (g/mol)	614.38	515.18	1240.52	1120.46	2652.93
a (Å)	11.456(4)	17.0562(13)	34.464(3)	14.6636(10)	13.3846(10)
b (Å)	11.456(4)	9.1844(7)	19.6386(18)	14.6636(10)	13.3846(10)
c (Å)	14.509(5)	12.9404(10)	13.7087(13)	14.6636(10)	15.7472(12)
α (deg)	90	90	90	90	90
β (deg)	90	90	90	90	90
γ (deg)	120	90	90	90	90
V (Å^3)	1649.0(12)	2027.1(3)	9278.3(15)	3153.0(6)	2821.1(5)
crystal system	trigonal	orthorhombic	orthorhombic	cubic	tetragonal
space group	$P3_121$	$Pccn$	$Cmcm$	$I2_13$	$I\bar{4}$
Z	3	4	8	4	2
D_c (Mg·m^{-3})	1.856	1.688	1.776	2.360	3.123
μ (mm^{-1})	7.427	8.039	7.065	10.378	17.292
$F(000)$	876	936	4640	2088	2392
T (K)	107(2)	100(2)	100(1)	173(2)	100(1)
refln indep	3374	4452	4679	2345	5362
refln $I > 2\sigma(I)$	3317	2554	3479	2292	5038
R_{int}	0.0300	0.0702	0.0753	0.0452	0.0349
R_1 ($I > 2\sigma(I)$)	0.0124	0.0363	0.0611	0.0179	0.0179
wR_2 ($I > 2\sigma(I)$)	0.0287	0.0818	0.1882	0.0376	0.0388

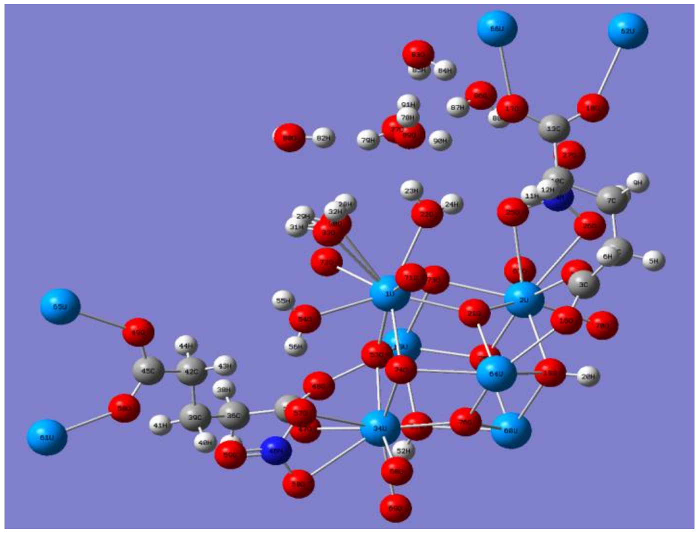

Figure 16. Shows CCDC#1556078 -Catena-[bis(μ-9pentanedioato)-bis(μ-hydroxo)-bis(μ-oxo)-dinitrato-triaqua-tri-uranium hexahydrate] [41](**Uranium**, **Nitrogen**, **Oxygen**, **Carbon**, **Hydrogen**)

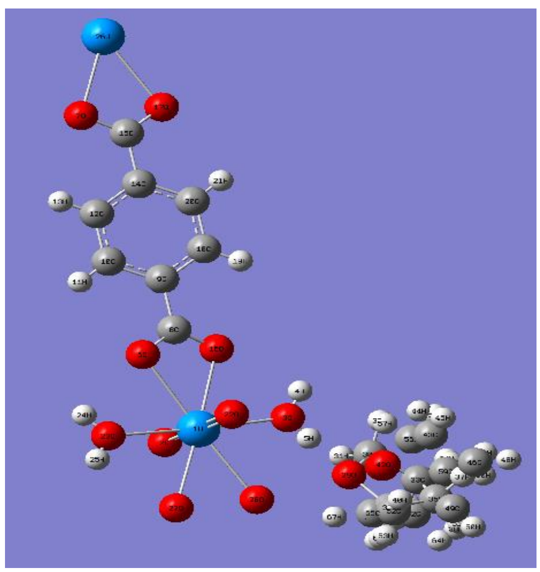

Figure 17. CCDC# 1556079 - Catena-[diaqua-[μ-benzene-1,4-dicarboxylato]-dioxo-uranium tetrahydrofuran solvate [41](**Uranium**, **Nitrogen**, **Oxygen**, **Carbon**, **Hydrogen**)

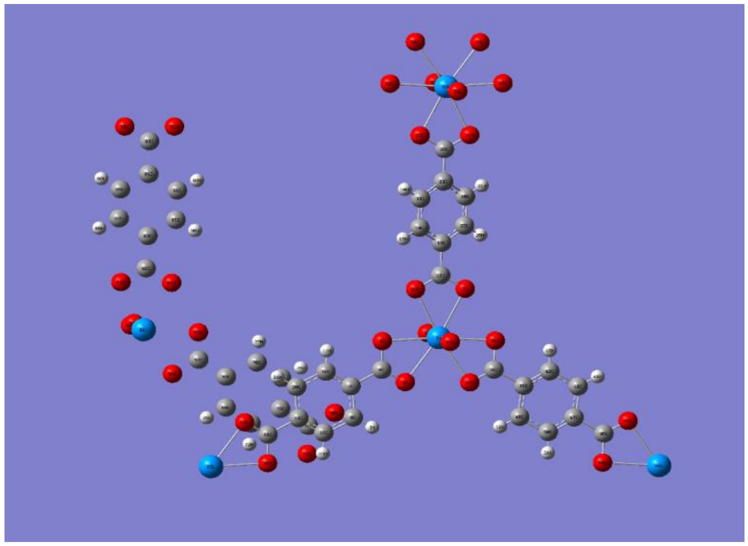

Figure 18. CCDC# 1556080 - catena-[di-sodium tris(μ-benzene-1,4-dicarboxylato)-tetraoxo-di-uranium nonahydrate] [41] (**Uranium**, **Oxygen**, **Carbon**, **Hydrogen**, **Sodium**)

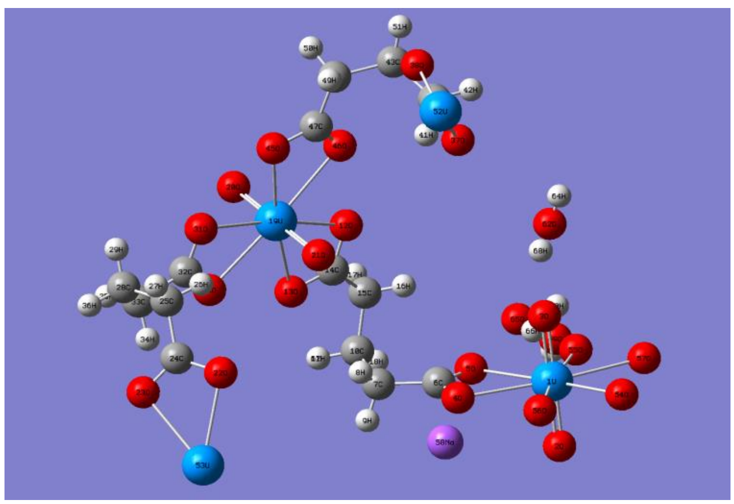

Figure 19. CCDC# 1556081 - Catena-[di-sodium tris(μ-glutarato)-tetraoxo-di-uranium octahydrate] [41] (**Uranium**, **Oxygen**, **Carbon**, **Hydrogen**, **Sodium**)

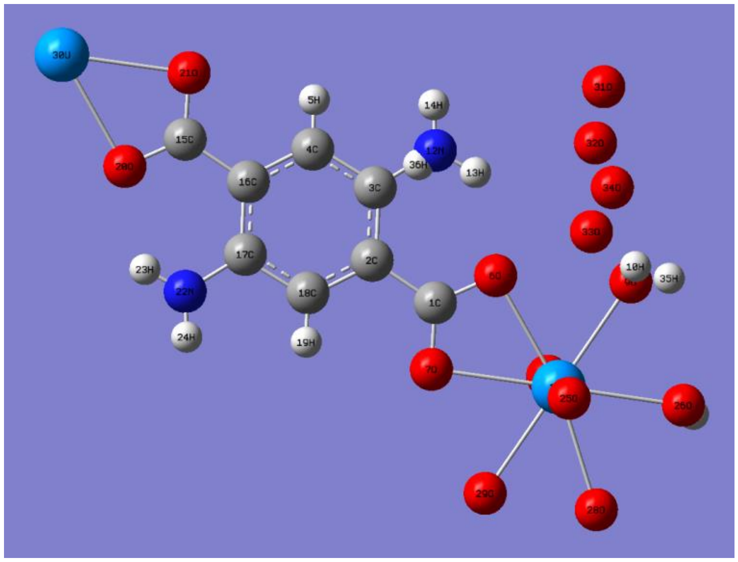

Figure 20. CCDC# 1556082 - catena-[[μ-2-aminobenzene-1,4-dicarboxylato] -(diaqua)-dioxo-uranium(vi) hexahydrate] [41](**Uranium**, **Nitrogen**, **Oxygen**, **Carbon**, **Hydrogen**)

B. 1.2. Composition of synthetic soil

Table 3. shows the basaltic compositions from APXS for different rover landing sites.

	Rocknest	Gusev	Meridiani
Number	1*	48†	29†
SiO_2 (wt %)	42.88 ± 0.47	46.1 ± 0.9	45.7 ± 1.3
TiO_2	1.19 ± 0.03	0.88 ± 0.19	1.03 ± 0.12
Al_2O_3	9.43 ± 0.14	10.19 ± 0.69	9.25 ± 0.50
Cr_2O_3	0.49 ± 0.02	0.33 ± 0.07	0.41 ± 0.06
Fe_2O_3 + FeO	19.19 ± 0.12	16.3 ± 1.1	18.8 ± 1.2
MnO	0.41 ± 0.01	0.32 ± 0.03	0.37 ± 0.02
MgO	8.69 ± 0.14	8.67 ± 0.60	7.38 ± 0.29
CaO	7.28 ± 0.07	6.30 ± 0.29	6.93 ± 0.32
Na_2O	2.72 ± 0.10	3.01 ± 0.30	2.21 ± 0.18
K_2O	0.49 ± 0.01	0.44 ± 0.07	0.48 ± 0.05
P_2O_5	0.94 ± 0.03	0.91 ± 0.31	0.84 ± 0.06
SO_3	5.45 ± 0.10	5.78 ± 1.25	5.83 ± 1.04
Cl	0.69 ± 0.02	0.70 ± 0.16	0.65 ± 0.09
Br (μg/g)	26 ± 6	53 ± 46	100 ± 111
Ni	446 ± 29	476 ± 142	457 ± 97
Zn	337 ± 17	270 ± 90	309 ± 87
Sum (wt %)	99.85	99.88	99.88
Cl/SO_3	0.13 ± 0.02	0.12 ± 0.02	0.11 ± 0.01

*Gellert *et al.*, 2013 (35); analytical uncertainty. †±1SD of average.

B. 2.3. Prototype soil system

Figure 21. Shows the prototype's timer dial which waters the plants at set daily schedules.

B. 3 Prototype Electrical Components

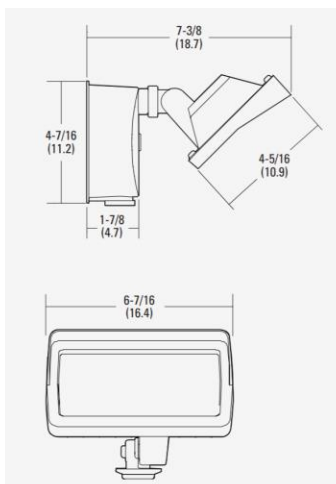

Figure 22. Shows the inner lighting inside of the greenhouse prototype.

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