The First Settlement of Mars

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Preface

There is an internet proverb: "We were born to late to explore the Earth and born too soon to explore the galaxy". While I agree with the logic, I disagree with the sentiment. We are at a point in human civilization, where we have developed the tools needed to start exploring. Perhaps we don't yet have the ability to travel between stars, but we can make the first step: Interplanetary Travel.

Mars is the next logical frontier for humanity. A world of unexplored potential, with mountains taller and valleys lower than any other in the solar system. It will challenge our technological abilities and pushes us to survive and adapt on the next most habitable planet to Earth. Mars has the resources needed to build and expand the first human landing into a colony, a city, a civilization. Unlike the moon where water and carbon are scarce, or Venus where minerals are unobtainable, Mars has plenty of both with an asteroid belt within arms reach, should colonists ever desire more.

As will be described throughout this plan, the initial colonization of Mars will be akin to the living standards of a developing nation. Luxuries will not be common and every day will be a battle to maximize growth, productivity and survivability over the course of a decade. This plan incorporates commonly agreed upon ideas and themes for the colonization of Mars and expands on them in a logical manner for a colony of 1000 people. This plan makes many sacrifices such as minimizing energy usage and water usage to redirect those resource to achieving the goal of self-sustainability in a shorter time frame. In most cases, this plan uses factual information to justify certain information, however, in other cases such information is not available and assumptions or approximations have been made.

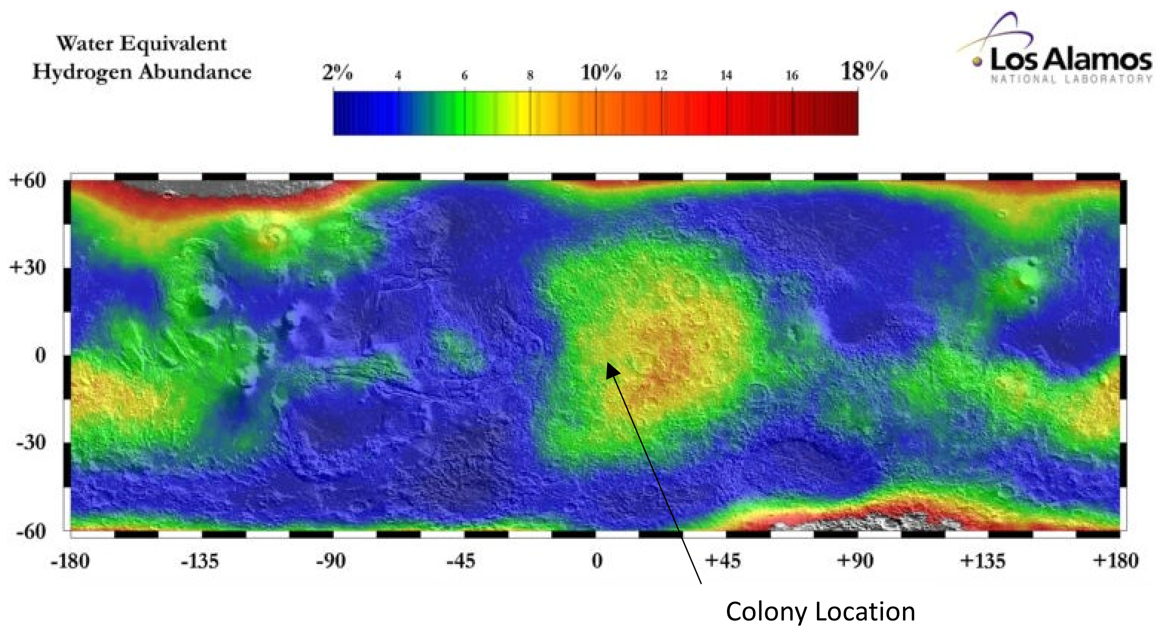
Colony Location

Power and Water. A Martian colony cannot grow without either. As a result, a Martian colony will be located in a region with a relatively temperate climate and easy access to water. Living on the cliffs of Olympus Mons may present a stunning view, but presents a limited quantity of water and higher power consumption requirements. Even on Earth, the global median distance to a source of water is 3km, as a result of people moving to cities near accessible water [1]. The world's most economically powerful cities are located near the water sources that have allowed them to grow.

Numerous locations were identified as potential locations for this colony. Some had plenty of water, some were closer to areas of research interest, some were located close to the equator and some would be visually appealing. Among these the notable locations: Acidalia Planitia presents plenty of water at the expense of a frigid climate; the Coprates Triangle Area has close proximity to Valles Marineris closeby while being in an equatorial region; and Meridiani Planum has water available (albeit less than Acidalia Planitia) in an equatorial region, but is not particularly close to the major geological formations.

Meridiani Planum is the location of choice for its water access and equatorial latitude. It was determined that despite its distance to locations such as the Valles Marinaris, Hellas Basin, or the Circum-Chryse region (where numerous outflow channels are present), long-distance rover trails and small outposts, would be more suitable for these geographically phenomenal locations. Travel to Valles Marineris or the Hellas Basin would take 2-3 weeks requiring 5-6 refill stations or “pit stops” along the way (every ~800km); trivial compared to the optimal 180-day journey required to get to Mars. Meridiani Planum is also the region where Opportunity landed, and it is not unlikely that the settlement would be named after a rover that exceed expectations.

Based on data from the Planetary Science Team at Los Alamos, it is expected that soil within this area has a water composition of roughly 8% [2]. This is visible in Figure 1. The approximate coordinates of the colony are 1.9462°S, 354.4734°E. This allows an improved water extraction efficiency in comparison to other areas which have a water abundance of 2%. And from data obtained by Opportunity, the expected temperature range is between +30°C (86°F) and -80°C (-112°F) [3]. With a proper insulation, this is easy to survive in and has been feasibly demonstrated by Earth Artic/Antarctic Expeditions which had to endure far worse.



Colony Timeline

It is important to understand the timeline and thus the level of investment required to build a colony capable of supporting up to 1000 people sustainably. It is unlikely and nearly impossible that 1000 people will be delivered to Mars on the first mission to setup this colony. The process of reaching this goal will take 10 years from the first rocket landing at Meridiani Planum. The colony will start with a setup phase, enter an investment phase, and after a moderate level of investment become self-sufficient and provide a direct return on the initial investment within 10-15 years. The initial basis for the colony will not be the first manned mission to Mars, but perhaps the second or third. Consequently, the development of Mars flight hardware is not included in the economic investment estimates.

Setup Phase

The setup phase will have an unmanned vehicle land in July of 2027 on Mars as an emergency return vehicle for the first 10 colonists, which land in September of 2029, approximately 2 years later.

This phase is responsible for placing the first ten settlers at Meridiani Planum. Their job is to build the first two housing units, farms and enough energy and water production for 100 people. This setup phase will be heavily based on Zubrin's "Mars Direct" plan. Zubrin predicted that an initial Mars mission would require a $30B budget, with each following mission costing $3B each [4]. Zubrin's "Mars Direct" uses only 4 people, which is unreasonably low to create sufficient food, water and shelter for the next step of 90 people. I propose that a team of 10 should be able to create the infrastructure to support a total of 100 people over 2.16 years (time until the next mission when they arrive) [5]. Conservatively, these initial foundation missions would cost $8B.

During this setup phase, the colonists will need to create farms, water extraction tools and shelter. In order to achieve this sustainably, production of a variety of materials will need to begin: polyethylene, polybutadiene, steel, aluminum, cement. With these materials, pressurized chambers, air locks, pumps, motors and piping will be created enabling the construction of the first in situ housing units and farms. The initial equipment imported from Earth will include a nuclear reactor cable of producing 100kWe, a Sabatier reaction chamber, a water electrolysis stack, a kiln or blast furnace for steel or aluminum production, a polymer reactor for either polyethylene or polybutadiene, plastic sheeting for the first greenhouse, crop seeds, 200 days of extra food before the crops grow, a Nitrogen generator, CO_2 scrubber, 10-15 space suits, water soil extractor and a water recovery unit.

Investment Phase

The investment phase of building the colony will involves setting up more housing, farming, vehicles, water production equipment, waste reprocessing, space suit and clothes production, more crop variety, and the first livestock on Mars. This phase begins 2.16 years after the initial colony founders land. At the beginning of this phase, the colony will have a total 100 people. These settlers will work towards building enough resources for approximately 400 people during the next Mars-Earth rendezvous.

The investment phase will begin preliminary mining operations, create trails to valueable research sites, begin developing intellectual property on Mars, selling of real estate (raw land and established property), while multitasking and continuing to build Martian homes and farms. For the first time, the Mars colony will expect small amounts of inbound cash flow, although they will not break-even for another few years.

This investment phase is an investment of colonist time and effort as the imports from Earth will decrease in value during this phase. During this investment phase, two rockets will land in November of 2031 carrying 90 additional passengers and additional equipment worth $250M. Afterwards, four rockets will land in December of 2033 carrying $100M worth of cargo. This is much less than the foundation missions that collectively cost $8B.

Self-Sufficiency

Self sufficiency will occur when the Martian colony can export at least 100 tons of minerals on every Earth-Mars transit. They will need to cover the $4.5M yearly cost of acquiring new computers, nuclear fuel, logic controllers, sensors and specialized medical equipment and drugs. At this point the colony should be producing a yearly mineral gross profit of at least $4.89B, have begun producing Earth-applicable intellectual property in the range of $500k and sold $750k worth of real estate to Earth.

The initial investment at this point, in 2036 will begin breaking even. It won't be until 2038 when profits will allow the colony to expand beyond the tight constrains depicted within this document. A 10-year return on investment is not bad at all for an enterprise this big, and is completely achievable assuming all missions are focused and properly coordinated.

Colony Design

With 1000 people living on the surface of Mars, the colony will be split into three sections: The Habitation, Industrial, and Spaceport Sections. The habitation section of the colony contains underground housing units, where each contains apartments capable of supporting 50 people. Above and surrounding each underground section, farms grow the necessary food requirements to sustain the population within. Each housing unit is templated to provide enough housing for the colonists and is connected through underground tunnel networks. Each housing unit is independent to the others providing individual life support systems, food production and distinct communities with each containing experts capable of running, repairing, maintaining each housing unit and organizing, feeding and caring for its members. The close proximity between each housing unit provides great redundancy for the colony and provides an opportunity for the colony to grow without losing a sense of community. The industrial section of the colony will contain centralized production of all materials used in the colony and will be distributed as needed. All resources except for water and power will come from the edge of a colony (out of range of its expansion). The Spaceport section will contain Take Off and Landing Pads, as well as storage for propellants (both oxygen and methane) for spacecraft (such as SpaceX's Starship) and for exploration ground vehicles, most necessary local transportation will occur underground, which is spatially more efficient and convenient for Martian residents who already live underground.

In comparison, traditionally imagined Martian colonies typically include large hemisphere domes which are impractical despite their design aesthetics for three main reasons. First of all, the production of such a dome requires increasingly thick plastic or glass to maintain the pressure differential between Mars' atmosphere and the habitable pressure as well as the weight of the dome itself. Secondly, a hemispherical dome produces wasted pressurized vertical space and the higher surface area presents the opportunity for wasted energy loss through thermal conduction, convection and radiation, as well as gas leaks. Finally, such a dome provides increased health concerns from radiation for long term colonist. Radiation levels on Mars wouldn't be a problem for visitors from Earth who spend 2-10 years on the surface, but the cumulative radiation dosage would present a problem for a Martian colonist and would undoubtedly reduce their lifespan.

Instead, this Martian colony design is based on the principle of extracting water out of the soil and then redeveloping the holes that had been dug during the water extraction and turning them into apartments and buildings with a central "public park" looking out onto the Martian sky and bringing in natural sunlight into each apartment and building without direct long-term exposure to radiation. See Figure 2 for a visual depiction of a single housing unit.

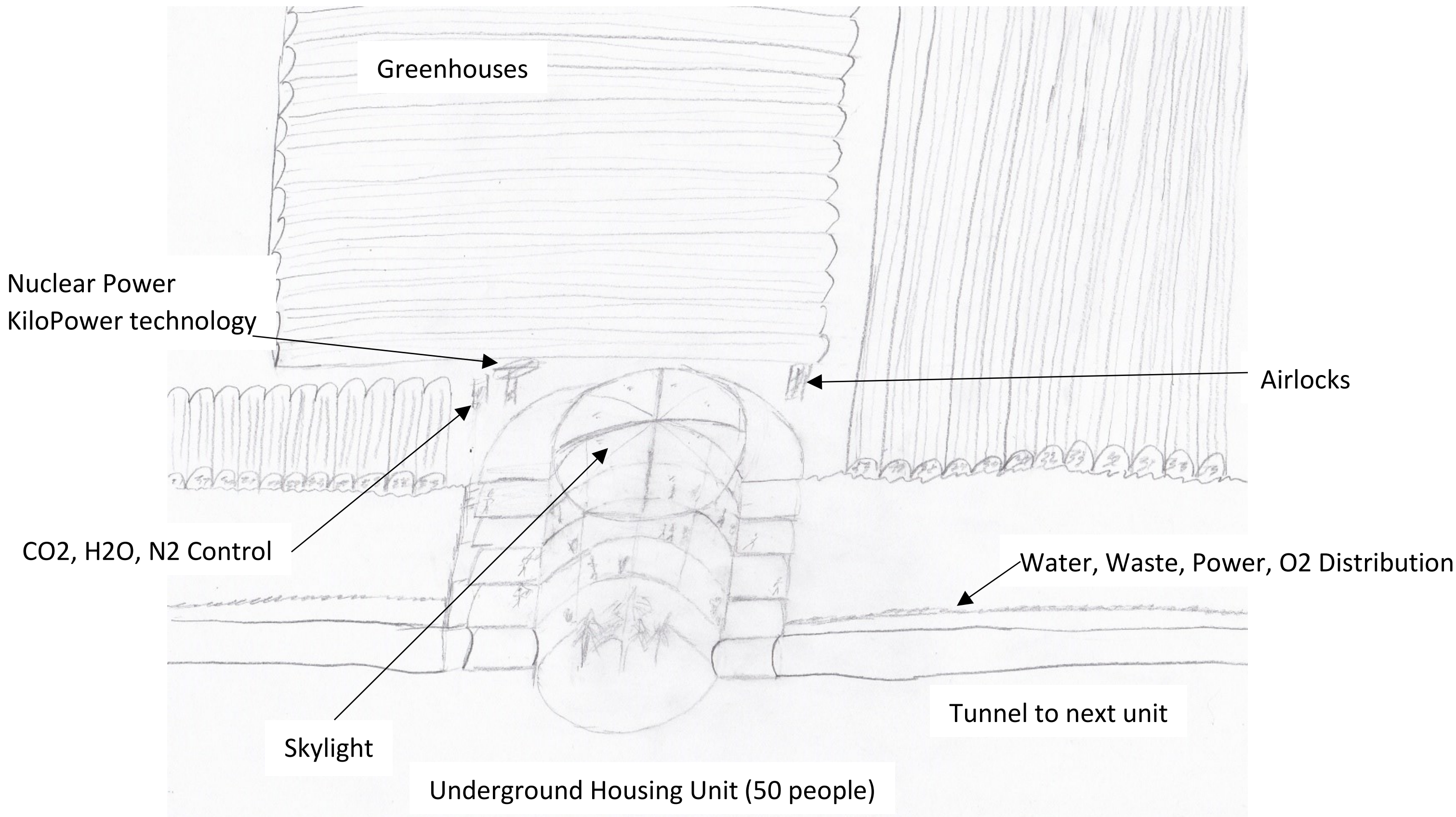


Figure 2: A freehand sketch of a single housing unit in the Martian colony

The Basics – Power, Air, Water, Food

Power, water and food are the three important material inputs that are required to sustain a colony. Power is required in large amounts, mostly to extract and provide sufficient water to the colony, where most of the water is used to grow food. Thus, we will examine the food requirements for a self-sustaining colony of 1000 people. Since male colonists require more food, an upper bound of 1000 male colonists will be used.

Food

Every person requires at least 1600kcal every day among a variety of other nutrients. A list of nutrients in Table 1. Depicts some of the important food factors and the minimum amounts required.

Table 1: Human nutritional requirements

Food Nutrient	Minimum Amount
Total Energy Used (kcal)	1600
Total Carbohydrates Used (g/day)	225
Total Fats Used (g/day)	44
Total Protein Used (g/day)	46
Total Fiber Used (g/day)	25
Vitamin A (mg/day)	0.9
Vitamin D (mg/day)	0.015
Vitamin E (mg/day)	15
Vitamin K (mg/day)	0.12
Vitamin C (mg/day)	90
Vitamin B1 (mg/day)	1.2
Vitamin B2 (mg/day)	1.3
Vitamin B3 (mg/day)	16
Vitamin B5 (mg/day)	5
Vitamin B6 (mg/day)	1.3
Vitamin B9 (mg/day)	0.4
Vitamin B12 (mg/day)	0.0024
Iron (mg/day)	19.3

The challenge lies in providing sufficient nutrition with a minimum amount of power and water. A selection of foods was analyzed for their nutrition, yield, water requirements and growth time using upper bounds from a variety of Earth agricultural literature [123 -123]. It is assumed that the sunlight reaching Mars (roughly 60% of that on Earth, 590W/m^2) is sufficient for the selection of crops to grow [6]. It was also assumed that it would take longer to grow. In each crop growth range, the maximum growth time was analyzed. By analyzing typical/average yields of each crop per hectare, the amount of water consumption was determined. Table 2 contains a summary.

Table 2: Crop varieties and suggested daily diet for Martians

Crop Menu	Daily Usage (g/day)	Growth Time	Yield (kg/hectare)	Water Demand (L/g)	Notes
Wheat	0	120-240	3100	1.45	
Soybeans	0	70	3100	1.45	
Lentils	0	80-110	1290	2.71	
Chickpeas	0	100	806	4.34	
Rice	0	105-150	5000	1.8	
Potatoes	1010	90-150	25000	0.2	Most Efficient Source of Energy/Carbs
Corn	0	90	10500	0.48	
Tomatoes	300	50-90	40000	0.15	

Sesame Seeds	99.18614721	100-130	1200	1	Most Efficient Source of Fat
Rapeseed/Canola	0	74-140	2500	1.8	
Kale	195	70-95	5000	0.7	Most efficient generic vitamin source
Other	**Daily Usage (g/day)**	**Growth Time (day)**	**Food Needs (g/day)**	**Water Demand (L/g)**	**Notes**
Eggs	200	1	565	4.11	Needed for Vitamin A, D and B12

Unfortunately, the above distribution is not the ideal diet. It will likely become very boring and it will be the job of the chefs in each housing unit to vary the preparation of the food on a daily basis. This selection of food is also not perfectly energy optimal. The simplex method energy optimal solution is to eat 0.73kg of potatoes and 2.3kg of tomatoes every day, which is a little bit ridiculous. As a result, the simplex method was used as a starting point and was then modified to the quantities of food as seen in Table 2.

It is also important to note that sources of Vitamin B12 will be difficult to produce for the colonists without supplements or sources of meat. As a result, eggs laid by chickens will provide the necessary quantities. Vitamin B12 deficiency in short-term (2 years) Mars missions would not be a drastic problem, however without a source long term, colonists would start to have serious medical problems at the 3 to 5-year mark of deficiency. Sourcing any of the required Vitamin B through import from Earth is not a suitable option since these vitamins are fragile and the 6-month trip through space would be logistically problematic. Chicken eggs provide a convenient source.

For this desired food balance, it was also determined that a 10% overproduction safety would be required to store as reserves in case of a dust storm which may ruin or prevent a crop yield. Based on the data of the most recent Mars dust storms, they occur approximately every 5 years for a duration of 4 months at most, a 6.6% percentage of potentially dark days. Artificial lighting was considered but immediately dismissed because it increases energy demand by at least a factor of 2000. The requirements for 1000 people are listed in Table 3.

Table 3: Food growth requirements for 1000 colonists

Total Water Requirements (m^3/day)	1435.882
Total Space Requirements (m^3)	233036.83
Total Nitrogen Fertilizer (kg/day)	5.34
Total Potassium Fertilizer (kg/day)	1.52
Total Phosphorous Fertilizer (kg/day)	2.05

It was determined that for every housing unit, 4 individual farms will surround the habitat with dimensions of 65 meters by 48 meters, with the width split into 12 tubular hemispheres and pressurized to 8psi with mostly carbon dioxide. Splitting the farm into hemispheres reduces the thickness of the required plastic. The farms will be built with 17.8mm thick Linear Low-Density Polyethylene (LLDPE). LLDPE can be easily created on the Mars from Ethylene (and thus atmospheric carbon). LLDPE is a transparent plastic, vital for the planet to receive enough sunlight. However, it has a high gas permeability compared to many other plastics. Fortunately, the greenhouses will contain a mostly carbon dioxide atmosphere and thus the diffusion gradient can be overcome with atmospheric resupply. Poly(ethylene terephthalate) would be a better choice since it is transparent (as used in water bottles) and the Glycol version can easily also be 3D printed. However, the additional Terephthalate component is difficult (but not impossible) to create without oil. The same is true for most of the other transparent polymers, which require organic feedstock or oil, both of which are energy intensive to make and not an ideal for a colony whose goal is to become self-sustaining as soon as possible.

Water

With food requirements precisely quantified, the water requirements quickly fall into place. Even on Earth, household and industrial water usage pales in comparison to water usage in the agricultural sector. Water distribution was calculated across each sector to determine total water requirements for the colony. Thus, on a daily basis, a colony of 1000 people will consume 1850 kg of water every day, as seen in Table 4.

Table 4: Water usage by Martian colonists

Process/Application	**Water Usage (L/day)**	**Water Usage (%)**
Food Production	1435882.181	77.608
Household Water	89002.85714	4.811
Industrial Products	318311.039	17.204
Fuel, Transportation and Oxygen	6975.18899	0.377
Total Required	1850171.266	100
Recyclable Water	1524885.038	78.298
Water Processing	-1850171.266	-100
Soil Distillation	-401530.4799	-21.702
Water Recycling	-1448640.787	-78.298

As discussed earlier, based on the location of the colony, we can expect at least an 8% soil water content. It has been established that the heat capacity of Martian regolith is approximately 600 J/(kgK) [7]. As proposed by Zubrin, 500°C would be effective in releasing the trapped water [8]. The daily temperature varies wildly [3], but assuming the average day time temperature to be 0°C, releasing the water from the soil would require 1.04kWh/kg of water. Re-condensation could be easily accomplished by flowing cold water through a condenser apparatus (the water cooled through a heat exchanger with the Martian atmosphere, which would need to remove 0.58kWh/kg of heat energy from the water. Zubrin estimated 3kWh/kg energy consumption for 4% soil [8]. Using 8% soil, 1.62kWh/kg of water is reasonable with 5.019 tons of Martian regolith being processed every day. An added benefit of extracting water from Martian regolith is that the soil would also reduce any toxic perchlorates typically used as an excuse against colonizing Mars. This soil would be reused in farms or turned into cement/brick and used to build the habitats where structural strength is important, but excessive in comparison to steel.

Excavating 5.019 tons of Martian regolith would be nearly enough space to build a housing unit and farm. Housing units require moving up to 5500m^3 of regolith. With a density close to 1kg/m^3, 91% of a residential unit capable of housing 50 people would be excavated in a single day. The resulting water would be piped through the already existing water network which would expand with every new addition to the colony. The water distribution system will be a decentralized network, where new water is injected into the housing units at the edge of the colony and redistributed. Each housing unit would recycle their own water. The industrial sectors extract water from this network. This decentralized system would automatically adjust to provide water where it is needed.

Due to the energy expense of extracting water, drastic conservation and recycling techniques will be used. Water vapour will be controlled within habitats and farms; waste water from showers, toilets and sinks will be concentrated; clothes washing, food preparation, waste vacuum drying (including fecal matter, which could also be used as a biofuel power source) will be employed to recover as much water as possible. With best efforts, a 95% water recycling efficiency should be attainable within food production and household water use. Industrial products will also employ water recovery techniques, but water converted into hydrogen and oxygen and incorporated into materials and products will be unrecoverable. Likewise, water produced from the combustion process used in transportation on rockets, or in long-range exploratory vehicles will be unrecoverable.

Air

You can survive 3 weeks without food, 3 days without water, but only 3 minutes without air (oxygen) [9]. The air within habitats will closely mirror the atmospheric composition on Earth.

The oxygen supply will be dependent on the industrial processes taking place outside of the colony. The production of methane and oxygen creates enough excess oxygen to support the colony. There will be a steady source from any refueling stations for mars terrain vehicles or rockets returning to Earth with cargo important to the economic self-sufficiency of Mars.

The nitrogen supply will be monitored and altered at each residential unit. Most nitrogen loss is expected to be lost through airlocks. Airlocks will pump down to 600Pa (approximate Mars atmospheric pressure) [10], but will not achieve a full vacuum and some valuable Nitrogen will be lost each time. A combination of CO_2 freezing and zeolite pressure swing adsorption (PSA) will provide nearly pure Nitrogen. The CO_2 freezing is required because it competes with Nitrogen for adsorption sites at significantly relative pressures. As an upper bound, it was assumed that every person in the colony will use an external airlock twice a day once to exit, once to re-enter. 2 airlocks are available for each residential unit. With this protocol in place, it is expected that 65.9kg of nitrogen would be lost each day. 10.14 kWh/day of power are estimated to replace this Nitrogen effectively. However, 2152kWh/day will be used to pump the airlocks, it may be more beneficial to only partially pump the airlocks and release the rest to the atmosphere or employ clever energy recovery technology into airlocks. A similar system will provide nitrogen reactants into the Bosch-Haber and Ostald Process to create ammonium nitrate as a fertilizer for the farms.

The carbon dioxide will need to be removed from the air as it is a waste product of respiration and begins to affect humans negatively above a 0.1% concentration [11]. The International Space Station uses a module called the Carbon Dioxide Removal Assembly based on zeolite sieve beds, however most of the power consumption of this assembly is used to *completely* remove moisture from the air prior to separating out the carbon dioxide. This is incredibly inefficient. As a result, recent research in low concentration carbon dioxide removal for space travel has resulted in electrochemical membranes powered by an electrical diffusion gradient. They are 4 times more energy efficient with an energy consumption of 0.525kWh/kg of CO2 and extremely selective for carbon dioxide over nitrogen [12]. Although the technology is not yet perfect (long term stability issues), it is useable and will be rapidly improved by the colony. Creating this membrane will be challenging for an early colony, but will fairly easy once aromatic compounds be created. Alternatively, a zeolite system similar to the nitrogen generator could be used, but would result in excessive nitrogen loss due to its prevalence within the pressurized environment. These CO2 membranes are lightweight and will be imported in the short term.

Power

Sufficient power to sustain the operations of the colony will be vital. A power failure without backup options could be fatal. Only two major power sources suitable on Mars exist: solar or nuclear. Nuclear will undoubtedly provide consistent power on demand. Solar panels could not be imported in sufficient quantities to justify the cost. Nuclear is not inexpensive either, but the compact energy source is easier to fit on a single rocket, rather than stacks and stack of solar panels. Solar panels would have to be produced by the colony once they have mastered precise silicon production and doping, which is beyond the capability and resources of a 1000-person colony.

The breakdown of energy usage within the colony is shown in Table 5. It is evident that the two biggest power hogs include food growth and fuel and transportation. Fortunately, most of the food growth energy requirements is provided through heating (through waste heat energy of the nuclear reactor). Even with the rather large heating requirement of the greenhouses, the nuclear reactor still produces extra heat energy in comparison to the amount of electrical energy it generates. The main reason for electrical power usage is the synthesis of methane and oxygen for rocket fuel and vehicular transportation.

Table 5: Energy Usage of the Martian colonists

Process/Application	Electrical Energy (kWh/day)	Thermal Energy (kWh/day)	Total Energy (%)
Life Support	2804.24	1119.66	2.182
Food Growth	41.42	90163.65	50.17
Water Production	0	1561.02	0.868
Industrial Products	4.16	472.79	0.265
Mining	77.44	0	0.043

Fuel and Transportation	83550.45	0	46.47
Total	86477.71	93317.12	100
Nuclear	-86477.71	-374448.47	-256.36
Net Total	0	-281131.34	-156.36

In order to power the fission reaction: Uranium-235 would be imported for roughly $630 per kilogram including enrichment, conversion, fuel fabrication and transportation [13]. To satisfy the above requirements, a nuclear reactor 360 times more powerful than NASA's KiloPower project is required [14]. KiloPower is designed to produce 10kW of electric power. This colony would need 3.6MW. The fissile mass required to provide this much power would be 15.7 tonnes of Uranium-235. This could fit on a single launch of a rocket to Mars, and would only be a fraction ($1/11^{th}$) of the up-mass for the planned, but not yet built SpaceX Starship.

The fissile material would cost $9.9 Million. It is reasonable to assume that the necessary reactors would cost approximately $15 Million, excluding the development costs from the KiloPower project and any scale up work needed. In order to deliver the thermal energy effectively to all the greenhouses, it would be ideal to have one reactor per residential and farming unit. The electricity generated would supply each unit as well as the industrial processes and rocket refueling depot.

The Material World

A variety of materials will be needed for a Martian colony, but a lot can be completed with very little. Basic metals, plastics, ceramics and composites, and various chemicals will be the basis for this new society. Among metals produced, a Martian colony will produce and use steel, stainless steel, iron, and aluminum. Among plastics produced, polyethylene and polybutadiene will be important. Among ceramics and composites, glass and Martian cement will be frequently used. All of these can be easily produced and all the components have been determined to exist in Martian soil or atmosphere. The one resource that will not be abundant is paper or any other organic products. Colonists will have to simply use tablets for all written communication and use a bidet or water gun after their visit to the washroom.

Metals

The most used metal will be steel. It will be used for making structural support beams for both the underground habitats and the surface greenhouses. It will be an important part of airlocks, pumps, some industrial piping, mining bits, pumps and motors, cooking utensils and resistive wire.

Aluminum will be used to create cheap wiring, in case copper is not available and will be used in applications sensitive to weight, such as bikes and cars.

Both metals can be created by combining the oxide found on the Martian surface with carbon monoxide to reduce the metal into a useable form.

Plastics

Polyethylene and polybutadiene will be the main two polymers used due to their versatility and ease of production. Polyethylene can be created from carbon monoxide and hydrogen gas.

$2CO + 4H_2 \Rightarrow C_2H_4 + 2H_2O$

Polyethylene will be heavily used within the colony. It is expected that 247 tonnes will be produced every day to maintain a rapid building pace and be able to provide living quarters for the next Mars expedition. Polyethylene will be used for the greenhouse windows, flooring and walls in the residential units and piping for water and waste. Polypropylene will also be available, however in much smaller quantities.

Polybutadiene will be significantly rarer, as it requires butadiene and will be a rare side reaction of the above chemical process. Nonetheless, it will provide an important elastomer material which will be used in creating airlock seals, mechanical counter-pressure suits, gaskets, drive belts and tires. The different monomer fractions will be separated through a distillation process.

Ceramics and Composites

Glass production will be used to create windows on each of the living quarters and create a pressurized window on the habitat unit. It will be produced from the waste materials of the steel production process. The Martian regolith will have the iron oxides removed for making steel with magnets, thus leaving silicon dioxide for glass making. The silicon dioxide will be heated to super hot temperatures before it turns into a liquid and later becomes transparent. 2.4 tonnes of glass will be created every day.

Martian bricks made from the regolith will be used in conjunction with steel when building new habitats. The bricks will be used to reinforce excavations and prevent collapse-ins. Regolith that has already been dried and had its perchlorates removed will be finely ground, wet, recompressed and dried by a hot thermal vent redirected from the nuclear reactor.

Mining

One of the main ways through which this Mars colony will sustain its self is through mining and export of high value ore. Robert Zubrin showed in 1990 paper that high value metals would be worth exporting from Mars back to Earth [15]. Indeed, the value of mineral exports is very likely to be a successful business model for two main reasons. On Earth, most surface ores have been scavenged and it is progressively more difficult to mine. Secondly, on Mars a lower gravity and colder surface temperatures allow deeper excavations, easier mining excavations and reduced power consumption. Current records for mining on Earth reach 4 kilometers in South Africa, where the temperature reaches 60°C [16][17]. It is expected that the Mars' geothermal heat flow (or rather aerothermal) is between 25% and 42% that of Earth. In combination with the reduced gravity, mining operations could operate up to 10km below the surface of Mars. This drastically increases the chances of precious metals and undoubtedly increases the mineral availability in the solar system.

Based on a separate analysis of 2018 supply and demand, it was determined that (in order) the best minerals for mining and export to Earth are: Gold, Palladium, Platinum, Rhodium, Rubidium, Silver, Thulium, Iridium, and Germanium. All other metals have an extremely small demand or low market prices. 100 tons of equivalent amounts of the above metals would instantly make up the investment cost of setting up the colony. It is interesting to note that one of these mines got a $1B investment in 2017 [17], which is a significant portion of the investment required to establish this colony. Even with a transport cost of $200/kg, Table 6 depicts an example of the profits that could be secured from mining. Mining just 0.1% of the yearly Earth production quantities would produce a profit of $86.2B/yr. Albeit most of this profit comes from gold, but even without it $9.77B/year would be enough to finance the colony within a single year of the mining operation.

Table 6: Potential Profits from exporting high value metals

Exports	Earth Purchase Price ($/kg)	Earth Quantities (t/yr)	Expected Mars Price ($/kg)	Profit ($Billions/yr)
Gold	38189	3260	14520.53232	76.50720464
Palladium	34401	210	13080.22814	4.435362091
Platinum	26492	160	10073.0038	2.595039392
Rhodium	76840	30	29216.73004	1.422698099
Rubidium	14720	90	5596.958175	0.803073764
Silver	462	991.6	175.6653992	0.08560939
Thulium	6200	50	2357.414449	0.182129278
Iridium	31186	7.314	11857.79468	0.139903694
Germanium	1833	120	696.9581749	0.112325019

Exports, Economics, Investment and Cash Flow

Valuable metals are one of the exports that would make the Mars colony worth the investment. In fact, its proximity to the asteroid belt is a likely indicator that it may have a similar composition and ratio of elements. Certain asteroids have been determined to contain significant quantities of these metals. Asterank provides estimated values of many of these asteroids, of which many are within tens of billions to trillions of dollars [18]. However, we do not know for sure exactly what valuable metals are present and in what quantities, so let’s explore other potential exports to make the trip to Mars worth it.

Interplanetary Real Estate

Given a sanctioned system of government on Mars which would enforce property rights, land could be sold and would present tangible investment value to both the private equity firm, investment trust or the average joe. During the second phase of the colony expansion (between 2.16 years after the first manned rocket lands and 6.48 years later), people on Earth would see the progress of the colony being built. With a sense of organizational stability, adventure, and excitement, many would buy land or Martian housing and the colony could pay off its initial investment within 8.64 years of the first manned landing.

Market prices are difficult to predict, but let us assume that the land being sold is worth at least the market price of the metals that can be extracted from the soil within a depth of 10 meters (10kg) [19]. These are the only values we currently know about mineral deposits.

Table 7: Soil composition and minimum land value

Metal	Quantity (kg)	Market Value ($/kg)	Value ($)
Magnesium Oxide	0.75	0.3	0.225
Titanium Dioxide	0.1	2	0.2
Chromium Oxide	0.05	4	0.2
Manganese Oxide	0.05	1.5	0.075
Iron Oxide	0.2	0.2	0.04
Nickel	0.5	20	10
Zinc	0.3	0.5	0.15
Total	**1.95/10**	-	**10.89**

Based on just the mineral content, every square meter is worth at least $11. A fair market price would be $15/m^2. If the land has been developed into a habitable area, especially in a colony which may become an economical and technological hub in the future, the land value could be worth at least double the value of the minerals in the ground. An appropriate price would be $30/m^2. In order to finance this colony, 556 km^2 of undeveloped land would need to be sold or 278 km^2 of developed land. In the grand scheme of things, it would be a small price to pay for a Martian colony. For comparison Gale Crater is 156km in diameter and thus roughly 18626 km^2.

Intellectual Property Export

With the numerous environmental challenges that colonists will needed to overcome, intellectual property will most definitely be created as each challenge is solved. If intellectual property is developed and licensed or replicated on Earth, the Martian colony will need to take a percentage of the profits from the IP, effectively taxing the residents of the colony on their personal achievements and exports to Earth. Any IP royalties should be a reasonable amount as not to stifle but rather encourage innovation. A 10-25% stake seems appropriate to take from IP profits.

It is expected that Martians will be incredibly effective at developing technology in the following areas: Nuclear Energy (Fusion), CO2 Capture, Separation and Electrolysis, Mining, Rocket Propulsion, Genetic engineering, Water recovery and conservation, Water electrolysis, and oxygen sensitive chemistry. An appropriate scientific or engineering advancement could make a multi-billion-dollar market feasible: a breakthrough in fusion energy or solution to global warming or the ability to access deeper mines on Earth.

Research Tourism

Universities and research organizations will undoubtedly send individuals and teams to Mars. Although residents will receive accommodations, food and water for free due to their daily responsibilities within the colony, research visitors will need to pay for the resources they use. Splitting the investment cost among 50 yearly visitors with each institution paying $1M, would make a small dent in the initial investment, and could over a century to make a return on investment. This however, is not a sustainable solution as the novelty of the research will wear off over time. As part of this potential revenue source, Martian rocks could also be exported for study back to Earth or even as novelty items.

Investment and Cash Flow

Through an analysis of the equipment needed to set up the first colony for the first hundred people, and up until productive mining is established, it was determined that the required capital investment into the project will total around $8.25B, most of which is spent on the first colonists and their foundation expedition. Beyond the first two missions, it is expected that further colonists will be able to fund their own fare to Mars and the remaining capital equipment will cost less than $350M. Once the colony becomes self-sustaining it is expected that regular shipments (every two years) will total $9M for electronics and medical supplies. By the time this occurs, precious metals are expected to be shipped out to recuperate the invested financial assets. Also, at this time, the colony will begin to experience more financial freedom and will be able to explore into new areas of science and research that were not previously priorities. The first successful Martian companies will begin to flourish at this time as well.

Table 8: Cash Flow Projection for Martian Colony with mining as primary export

Year	2027	2029	2031	2033	2036	2038
Revenue						
Revenue from Resource sales	$ -	$ -	$0.00	$1B	$9.77B	$18B
Revenue from Real Estate sales	$ -	$ -	$0.00	$0.00	$750K	$2.5M
Revenue from IP sales	$ -	$ -	$ -	$ -	$500K	$1M
Revenue from Loans/Investment	$8.25B	$ -	$ -	$ -	$ -	$ -
Total Revenues	**$8.25B**	**$0.00**	**$0.00**	**$1B**	**$9.771B**	**$18.004B**
Disbursements						
Mission Imports	$3B	$5B	$250M	$100M	$9M	$9M
Total Disembursements	**$3B**	**$5B**	**$250M**	**$100M**	**$9M**	**$9M**
Opening Cash Balance	$0.00	$5.25B	$0.25B	$0.00	$900M	$10.663B
Add Total Cash Revenue	$8.25B	$0.00	$0.00	$1B	$9.771B	$18.004B
Deduct Total Cash Disembursements	$3B	$5B	$250M	$100M	$9M	$9M
Closing Balance	$5.25B	$0.25B	$0	$900M	$10.663B	$28.657B

The above cash flow projection corresponds to the transactions completed every time a rocket lands on Mars. In July 2027, an unmanned rocket will be sent as an emergency return vehicle and it will contain spare parts and automatic propellant production. On September 2029, the first ten colonists will arrive to set up the settlement. November 2031 will add 90 people to the colony. December 2033 will add 300 people, and in February 2036, 600 people will arrive and the colony and the total population will hit 1000 people. In 2038, the colony will have a total of 2600 people, and with mining operations underway, real estate sales and initial IP licensing, the colony will be cash flow positive. At this point, the colony will likely choose to invest in new projects relating to further colony expansion and sustainability.

Politics – A Socialist's World

The colony will be heavily focused on rapid expansion and although there will be decision makers, the political systems will be simple. Every residential unit will have autonomy and every resident within each unit will receive basic common services. It is expected that within this design, the colonists will naturally evolve into a Direct Democratic Socialism. Everybody will have a direct influence on the decisions being made, but given the difficulty of growing food or finding water on one's own, a social structure will form by which cooperation and sharing are strongly encouraged. I suspect that leaders within each residential unit will become representatives for the members of their housing unit within the greater colony. Within a colony of 1000, 20 people will be in charge of understanding the needs and wants of the community.

Conclusion and Further Thoughts

Growing a Martian colony will be difficult. There will be many technical and economic challenges to face amidst the battle to survive. I've outlined a way to make such a colony economically feasible within a short amount of time. The most probable and likely source of self-sustainability will be high value metal and mineral deposits. With the right sensors (gravimetric, magnetic, seismic) and machinery these could be detected and mined on Mars. It would allow the colony to expand beyond a 1000-person settlement into the first and perhaps one of the biggest cities on Mars.

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