"Dorothy's Long Day at Twin Planitias"

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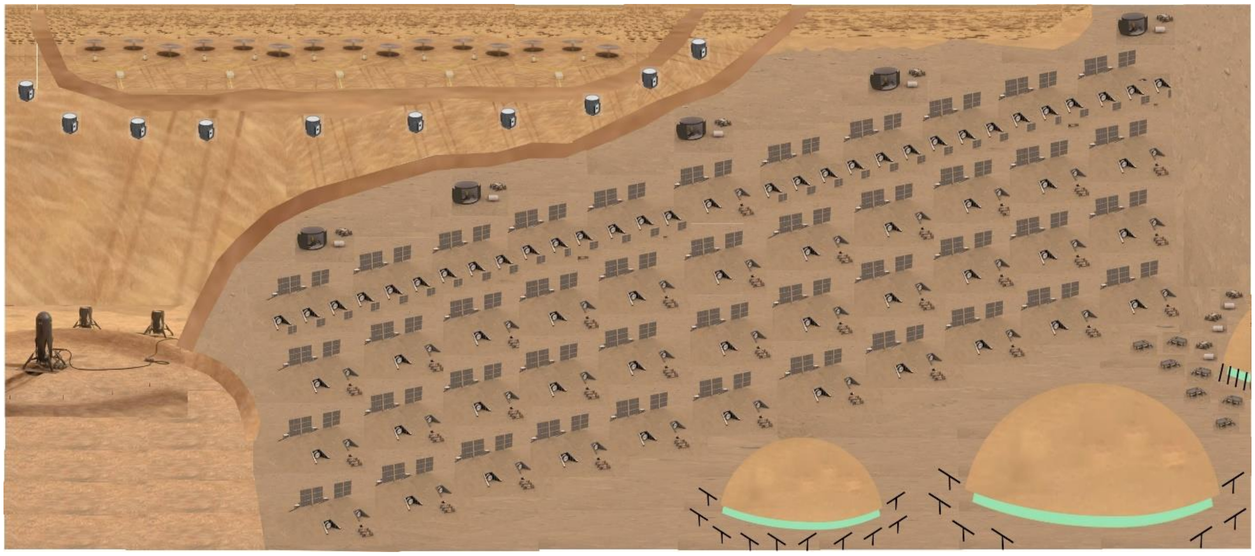


Earth was enjoying 9 decades of Apollo. An explosion in aerospace technologies drove down costs of new capabilities. Hundreds upon hundreds of people had set foot on the Moon. Population of Mars grew to 1000 and is integral to the survival of all species.

Terrestrial Earth needs have taken root on Mars. Goals for more habitable volume, especially common spaces, led to a tripling of per capita metrics, resulting in drastic ramp up of industrial base predominantly In Situ Resource Utilization (ISRU), Construction, and Manufacturing. Environmental Control System demands and trash growth necessitated policy changes and new technologies, many developed and tested on the Moon already. Education is paramount for all children to understand life on Mars and for adults to maintain a basic understanding of the rapid changes. All courses were online and monitored by a master. Each course included a lab for demonstrating clearly the student's understanding of the material. Some labs were far simpler than others depending on their degree of difficulty. Students often retook an exam until passing it 100% twice in a row. Completion of the most difficult subjects was honored with a merit badge. The courses got harder with age, much like degrees programs on Earth. However, nobody cared about your degree if merit badges had not been earned on Mars. Each student's talents were demonstrated for all to see weaknesses and strengths. Work assignments were determined accordingly. Establishing a steady water supply on Mars was one of the first systems deployed on Mars and was also the first system to receive an A.I. (artificial intelligence) overlay to reduce labor time and maintenance downtime. This A.I. became the case study taught in school. All adults were proficient in A.I. and monitored A.I. systems continuously.

The origin of the water was determined during the science precursor missions of human exploration zones by NASA to verify hazards and resources. This site was chosen because there was a verifiable 60-meter deep ice lake that was easily accessible beneath a shallow layer of regolith overburden. The site was located on the eastern tail of Erebus Montes on a subtle ridge straddling Arcadia Planitia and Amazonis Planitia. Several Rodriguez Wells ("Rodwells") pumped water, in briny form to prevent freezing, from the ice lake in buried triple-redundant water lines to storage tanks by the habitats. Each system refilled 2000-gallon storage containers several times between failures or clogs. Desalination and purification occurred inside conditioned spaces adjacent to the habitats and greenhouses. Many parts including valves and cleanouts were made of plastic to increase operational time in the corrosive environment and to allow for repairs with 3D printed parts using plastic feedstock made on Mars with printers brought from Earth originally. Fischer-Tropsche and Sabatier Reactors ran full time to produce hydrogen, oxygen, ethylene, and methane. Methane was easier to store than pure hydrogen that was loaded into fuel cells for immediate use. Redundantly, water and carbon dioxide were electrolyzed to produce breathable air buffered with nitrogen from Earth to meet demand. Kilopower (KP) fission nuclear device powered the water supply system. The same mobile utility equipment (MUE) that trenched the water lines was used to pile up regolith to form a shielding berm around the KP farm after deploying the double-redundant underground cabling to the power management and distribution (PMD) units. These autonomous operational deployments had been rehearsed countless times on the Lunar surface with a simulated small ice pack. Additional capabilities that exploited Mars' abundant resources were implemented with each arriving crew on scheduled synodic periods.

To accommodate further growth, at Population 500, the colony implemented a City-based self-governance that included a mayor, vice-mayor, annex commissioners, and colony manager with staff positions. As more international astronauts arrived, diversity among living annexes was encouraged through housing and work assignments. On Mars, crew members were called "colleague" or "colonist". Now that the colony achieved a population of 1000, the colonists debated on expanding the governance model to include more State-like branches of government to better handle Mars' interplanetary interests. Some wanted to create a new flag, expand to a Federal overlay, and pursue a seat on Earth's United Nations Council. In general, their conservative nature prohibited adding government positions without clear justification. They would need to vote. A.I. systems were added routinely now as the colony expanded quickly. The increasing trade market required they that add some regulatory and monitoring positions to oversee orders and deliveries, for the sake of the colony's viability. A.I. processes conducted most of the tasks. These A.I. and robotic systems were heritage from similar systems produced and operating for many years on the Moon as part of an early "affordable bootstrapping" project that later became known as the Metzger Addendum. The race to achieve mouse-level A.I. ended quicker than expected. Everyone wanted to be a close second if not the outright winner of A.I. development and market penetration. The rush created some issues with direct insertion of Lunar systems at Mars. The recurrence of a computer glitch that could not be remedied without microelectronic supplies from Earth more than a year later placed many colonists on edge who demanded that trust in some A.I. systems be re-earned. That required colonists to monitor the A.I. systems around the clock until trust was restored. At Population 750, the needs to ensure A.I. was trustworthy took focus away from the colony's supply-and-demand chain creating chaos and blame. To avoid a breaking point, the colony agreed to create 5 new departments of ministry that would hold seats on the Council of Delegates. Department of **Governance** was responsible for ensuring among all colonists the equality to pursue opportunities, rules of conduct, and the enforcement of ethics and laws. Department of **Health and Safety** was responsible for food, consumables, sanitation, diseases, medicine, fire safety, EVA (extra vehicular activity) protocols, and building codes development and compliance. Department of **Education, Science, and Intellect** was responsible for education, degree programs, intellectual property, and science missions on and off planet, which included refueling depot for science missions heading beyond Mars. Department of **Arts, Sports, and Entertainment** was responsible for public programs for the arts, recreation, gaming, broadcasting channels including inter-planet-net (IPN), intra-Mars-net (IMN), virtual reality (VR), augmented reality (AR), and media content. Department of **Trade and Treasury** was responsible for tracking all production, harvests, imports, exports, currency, ensuring a healthy barter system for goods, enforcing intellectual property rights, balancing capitalism and research budgets, and distribution of wealth. Along with the mayor and the 5 Annex Commissioners, the 5 department ministers held seats on the Council of Delegates. The Vice Mayor served as the vote tiebreaker. By Population 1000, the colony was flourishing. A.I.-based checks and balances were working across all domestic systems. Council positions were selected through public elections based on demonstrated accomplishments. There was tremendous diversity in selections of opportunities and freedom to pursue any religion. There was no Department of Religion by intent.

Needs for surface power escalated mainly due to 3D printing with basalt fiber (BF) and for resource mining operations. Basalt fiber's strength is similar to Kevlar's, and its density nearly twice Kevlar's. Basalt fiber was easy to make from the plentiful basalt. The process only required about 5 KWh/kg for grinding, heating, and extruding to desired fiber size. Common to In Situ Resource Utilization (ISRU), producing structural items from basalt on planet was far more favorable versus bringing Kevlar from Earth, as long as surface power was available. Solar power was plentiful on the Moon but less than half as strong on Mars, which would require larger arrays and heavier concentrators to convert solar energy to the power levels necessary for construction. KP fission nuclear power units were easy to set up upon landing and could provide those power levels. The non-proliferation agreement with Earth prohibited the manufacturing of fission power units on Mars. Fission units had to be supplied from Earth on synodic periods. This regulation hindered growth and led to more manufacturing in Mars orbit where solar power was more abundant than on the Mars surface. This approach had many benefits when dealing with unwanted byproducts and pollution and for avoiding launch loads on items shipped back to Earth. The single-stage ISRU-refueled lander could land 20 metric tons (mt) to the Mars surface while delivering to Low Mars Orbit (LMO) about 5 mt. Payloads could be landed precisely and cheaply if needed on the Mars surface. However, the 5-mt upmass limit per lander motivated more asteroid mining and on-orbit refinement to meet demands at Earth and the Moon and refilling the orbiting fuel depots. Energy-intensive processes took advantage of solar energy and trash-pollution control in orbit to prepare resources for shipment to Earth or the Moon. Asteroid mining equipment was cheap, leveraging many decades of terrestrial autonomous mining operations. A 4-metric ton miner complete with solar power and spring canon could mine hundreds of tons in a synodic period. On the Mars surface, KP fission units were excellent for startup locations, but deterred expansion of the colony development in the direction of the KP farm due to large standoff safety buffer requirements. Once operational with large radiators deployed, the KP units were not easy to relocate. Solar panels were easier to maintain and required little to no safe zones. Solar panels could be placed on roofs to decrease wiring lengths and transmission losses to boost efficiency and increase system maintainability. Nuclear batteries called NTAC (Nuclear Thermionic Avalanche Cells) that convert radioactive energy into electricity became a favorite on Mars and the Moon. The scalable solid-state design provided power levels matching the KP units but without requiring the large standoff safety buffer distances. Hence, NTAC could be integrated into systems. Rovers, mining equipment, basalt grinders, hot basalt fiber (BF) extrusion plants, and construction-scale BF printers used NTAC. The Mars-Air battery was also useful for powering very small devices. It worked much like hearing-aid batteries that recharge during exposure to cabin air. The Mars-Air battery got its name because it recharged even when exposed to carbon dioxide.

Any product requiring manufacturing in micro- and nano-precision inside clean rooms, such as computer chips, are shipped from Earth and assembled at Mars into devices. Most systems that required chips originated from the Lunar Proving Grounds and Moon Base. High-use items and parts with low mean time between failures were manufactured on planet using ISRU, recycled, or repurposed materials. Mars and the Moon shared Intellectual Property (IP) rights on many items tied to Proving Ground (PG) opportunities. Most notably, the Lunar surface offered partial gravity, low temperatures, low pressures, and nearly full GCR radiation environments for testing Environmental Control and Life Support Systems (ECLSS), food growth, surface mobility, reusable lander concepts, habitation systems including shielding, and some In Situ Resource Utilization (ISRU) technologies. The largest cost savings occurred by implementation of a Lunar-Mars stepping stone development pathway for the reusable lander, allowing those high costs to be spread across more years to remain below a spending budget similar to the International Space Station, making Mars more "affordable". In some cases, it was cheaper to conduct trials on the Lunar surface since the A.I. and robotic manufacturing facilities on the Moon could modify prototypes and return to feasibility and verification testing in a matter of hours, not weeks.

At Population 1000, interplanetary trade was thriving for Mars. The Mass Balance System continued to work in Mars favor for exporting supplies to cis-lunar space. This system of checks and balances rose out of the Committee for Space Research (COSPAR) that governed the planetary protection policies and commercial space guidelines internationally. "No Harm to Earth" with respect to forward or backward contamination by substance transported by robotic and human activities in Space grew to include the affects of mass movement from the Moon and the Earth. Two key areas of concern were 1) that launching or slinging large amounts of regolith from the Moon for radiation shielding, oxidizer, and propellant mass would create a dangerous Space debris field that would hamper and risk operations in cislunar space; and 2) that if the mining activities on the Moon grew too quickly by billionaires attempting to become the first trillionaire via "millions of people living and working in space", then the gravitational forces between the Earth and the Moon that affected ocean tides and the Moon's orbit might be altered faster than the 3.8 centimeters per year currently, resulting in unwanted consequences for the Earth. It was true that the math for the latter illustrated that it would take hundreds if not a thousand years at current terrestrial mining output to relocate a significant portion of the Moon's current mass to affect the tides of Earth's oceans. But that argument paled in comparison to the potential for mission hazardous space debris around the Moon and the additional argument that what's on the Moon needs to remain on the Moon to support activities there. Stemming from Weinzierl's works, a philosophy to maximize "complementarities" while minimizing "assignment of responsibility and blame for debris" among commercial entities competing for business was adopted. This led to a vote within Congress that supported and approved into law the Lunar Preservation Act. Other countries soon followed. The Act governed how mass delivered to and from the Moon would be enforced. The Commercial Space Launch Competitiveness Act of 2015, a law granting property rights to the resources of a planetary body to "whoever gets there first" was modified to specify that "to possess, own, transport, use, and sell" on the Moon would require special licenses to ensure the origin of those resources. Several years later, the Lunar Preservation Act was updated to include the Metzger Addendum to allow shipments of Lunar A.I. and robotics to Mars. The Lunar Preservation Act basically established the benchmark of mass trade by using the ratio of the mass of the Earth to the mass of the Moon. Any deviation in mass from the benchmark would need to be short-term and compensated immediately. That policy led to the "81.6 ratio rule", which was simply the mass of Earth divided by the mass of the Moon, prior to the return of astronauts to the Moon. To compensate for each metric ton delivered from the Earth to the Moon for an intended stay exceeding 3 years, that mass needed to be compensated by either 1) reciprocating one-to-one that mass from the Moon to the Earth within a 3-month window prior to or after that specific delivery; or 2) honoring the mass balance ratio by delivering to Earth 81.6 metric tons per metric ton delivered "permanently" to the Moon. The former could be honored by simply sending salvaged equipment from the Moon to Earth or sending Lunar A.I. and robotics from the Moon to Mars or to the Earth-orbiting Space Yard under the Metzger Addendum. Even so, far more mass would go to the Moon than from the Moon. For the Moon and cislunar economy to grow fast, while constrained by the 81.6 ratio rule, required that mass sent to the Moon be quickly compensated by returning mass to Earth or its Space Yard according to the replenishment rules. Lunar Base growth required that the replenishment mass come from somewhere else other than the Moon. De facto response: from Mars or asteroids.

To enforce the Mass Balanced Trade System under the Lunar Preservation Act, the United States Space Force would track mass shipments within the inner solar system. Clever monitoring and AI systems were deployed. Protocols were established for how and when assets were tagged and inspected so to avoid impacting vehicle development schedules and launch commitments. Penalty for violation was revoking the company's licenses. Company assets would simply go to the competitors for pennies on the dollar, and those funds deposited in accounts to help fund the Space Force. Awards and merit scales were established to encourage compliance with the Laws. Anchor tenant term contracts was one of those incentives. There had been only one occurrence of bribery of a Space Force officer to omit a special delivery from Earth. The A.I. caught it immediately resulting in a court case, the firing of the officer, and the nullification of the offending company of its interplanetary trade licenses, all played out on social media. As a result, some guidelines were added for what would be considered mass that must be balanced initially by the 81.6 ratio rule. It was also agreed that any propellant mass that was expended prior to TLI (trans-lunar injection) remained with Earth. And, any propellant mass that was expended prior to TEI (trans-Earth injection) remained with the Moon or Mars. It was agreed that the massive reusable Galactic Cosmic Ray (GCR) shielding overcoats that remained in cis-lunar space did not count against the ratio. GCR overcoats reused interplanetary also would not count against the ratio. However, the propellant to place a massive overcoat into an interplanetary reusable mode was well beyond what anyone wanted to spend. An affordable opportunity for interplanetary reusable GCR shielding were being worked by Mars via asteroid mining that would not disrupt the Mass Balanced Trade System. Protocols for reducing mass that remained more than 3 years on the Lunar surface, termed "Lunar long stay", were expedited. Reusable large-scale landers were one of the first enactments. Lunar surface assets were designed so that they could be salvaged in Earth orbit for refurbishment, which led to the creation of an Earth-orbiting Space Yard (E-OSY) and 1:1 buy down of long-stay mass tracked in the 81.6 mass ratio column. The E-OSY was ideal logistically when cargo was received at Earth. There was simply no way to place in Mars orbit or push from Mars orbit to Earth the large masses necessary to keep pace with the 81.6 ratio rule. Instead, mined raw materials were deorbited with canon guns and reusable tugs from the asteroid as it passed near Earth and counted as "mass from Mars". Hence, cargo "arriving" from Mars was usually raw materials mined on asteroids in their "natural" orbits by operations "officed" at Mars. Cargo was inspected by the Space Force upon arrival at the Mars Orbiting Node (MON) and at the E-OSY.

There were many asteroids of all types with orbits passing by Earth and Mars with synodic periods under 24 months with orbital velocities slow enough to catch. There was rarely a need to redirect or alter the orbit of the asteroid being mined. Often, large quantities of nitrogen, phosphorus, and potassium mined from asteroids were delivered to Lunar surface greenhouses. According to the 81.6 ratio rule, deliveries like this required a companion delivery to the Earth-Orbiting Space Yard. Quickly, the E-OSY became not only the shipping hub but also the off-planet industrial base for Earth. As rare earth elements and ore of other precious metals arrived via Mars to Earth orbit, under the 81.6 Ratio Rule, it was cheaper to refine those raw materials in Earth orbit using solar power. Refinement needs increased demand for A.I. and robotics deliveries from the Moon. In most cases, it was cheaper to produce goods at the E-OSY, especially the microelectronic and nanoelectronics parts needed at Mars. The E-OSY grew quickly into the Earth-vicinity center of commerce, industry, and government (CCIG) for triangle trade within the inner solar system, requiring more A.I. and robotics from the Moon to maintain productivity. Demand for GCR shielding ballooned, and growth in asteroid mining followed lock step.

GCR shielding was not the only demand driving asteroid mining. Phosphorus, some on Mars, much on asteroids, often in the form of apatite, became more precious than rare earth elements and precious metals. Phosphorus is the least abundant element cosmically relative to its presence in biology. Phosphorus is an important structural element in DNA and RNA. Humans and other animals get their phosphorus from eating plants (or by eating animals that eat plants). On Earth, plants pull out phosphorus compounds from the soil, but a lot of this is recycled material from decaying organic matter. Earth's mines were running out of phosphorus. Oceans are now awash in phosphorus since strict erosion and sediment controls were not honored worldwide. However, cost-effective means to recover the needed quantities from the oceans had not been sustainable due to disposal costs of companion items without a commercial market, which could not simply be dumped back into the oceans. Mining asteroids for phosphorus was cheaper. To receive mined phosphorus, runoff catch basins were enforced worldwide which enabled phosphorus conservation and recycling terrestrially, further protecting Earth's oceans.

Apatite contains much phosphorus, most of the halogen elements, fluorine and chlorine, and hydroxyl (OH) groups that represent water. The first apatite grains formed when water and other fluids flowed through asteroids warmed by radioactive decay. Some asteroids were heated more strongly and melted. Apatite in those rocks was formed from the last drops of molten rock in cooling lavas. Lunar apatite also formed from the last drops of molten rock when lava cooled following its creation from a giant impact of a Mars-sized body, sometimes called Theia, with Earth. Apatite is abundant on Mars and shows that water, phosphorus, and the heat from igneous intrusions clearly came together throughout the history of Mars. In its natural form, Lunar and Martian regolith was inhospitable to plants. However, when combined with microbes, compost, and tenacious halophytes, phosphorus from apatite was vital to the sustainability of Lunar and Martian greenhouses to meet food and other demands.

After the initial crew set up the habitation systems needed by the crews arriving during the next 2 synodic periods, they began an extensive exploration project to locate sources of accessible apatite. Their search led them to the nearest lava tubes along the ridge line that overshadows the colony. Apatite lined the lava tubes and was easily mined. Mining the lava tubes also resulted in accessible and habitable caverns, chambers, and walkable tunnels. The apatite was stockpiled over time. Using the e-beam elemental extraction system proven on the Lunar surface, phosphorus was made available for the greenhouses. Mars had taken Geissler's call for an Earth-based circular economy for phosphorus to an interplanetary level of trade. By shipments of phosphorus and other asteroid-mined resources, Mars routinely supported Lunar greenhouse activities for supplying the Earth-orbiting Space Yard with fresh food and other supplies. Many items from Mars could arrive in Lunar orbit using propellant-less Ballistic Orbit Capture based on orbital mechanics that took advantage of the Earth-Moon Weak Stability Boundary, rather than synced with synodic periods for minimum energy transfers that require larger amounts of propellant. The asteroid miner's canon pushed large amounts of resources to Earth and the Moon while the mined asteroid passed through Earth's vicinity and cislunar Space. Each canon load reshaped the asteroid's orbit.

Trade Table Based on Mass Ratios	**Replenishment Ratio Rule**
From Earth to the Moon, M_E/M_{Mo} = 81.6 (“81.6 Ratio Rule”)	Transportation Cost = $0/kg*
Initial Mass, Non-Reusable (All mass Long Stays on Lunar Surface) Reusable Lander (Payload Mass Long Stays on Lunar Surface)	< 3 months*****, Moon to Earth = 1:1; Moon to Space Yard = 1:1 > 3 years, Mars to Earth = 81.6:1
From Earth to Mars 1:1 (Unaffected by the “81.6 Ratio Rule” as long as replenished within 1 synodic period)	Transportation Cost = $500/kg
Initial Mass, Non-Reusable (All mass Long Stay) Reusable Lander (Only Payload Mass Long Stay)	Mars to Earth = 1:1
From Moon to Earth	Transportation Cost = $0/kg*
Food and A.I. to Earth-orbiting Space Yard	Moon to Space Yard = 1:1
From Moon to Mars	Transportation Cost = $500/kg
A.I. and other systems under shared intellectual property (IP) agreements with Mars	Moon to Mars = 1:1 Reduces Moon’s obligation to Earth Replenishment Above
From Mars to Moon “81.6 Ratio Rule” Applies to Compensate for Long-Stay Mass from Earth to the Moon	Transportation Cost = $200/kg (propellant or propellant-less)
Reusable Lander (Payload Mass stays on Lunar Surface)	Mars to Moon = 81.6:1
From Mars to Earth	Transportation Cost = $200/kg
See Mars to Earth and Mars to Moon Rules	
Preferred/Needed Goods: ○ **Earth** preferred deliveries of rare earth elements, ore of precious metals, phosphorus, and GCR materials for Orbiting Space Yard ○ **Mars** preferred deliveries of Kilopower fission units, micro- and nanoelectronics, asteroid miners, rovers, and new food and plant species that thrived in Lunar greenhouses ○ **Moon** needed deliveries of plastic feedstock for 3D printers, fertilizer (Nitrogen, especially Phosphorus to enhance fruit-bearing and boost yield, and Potassium), water, brine/salt for aquacultures and food storage, and micro- and nanoelectronics	***** Liberal Exportation Timeline allowed for Food from Lunar Greenhouses to Earth-orbiting Space Yard. Earth-Moon and Moon-Earth Transportation Cost = $0/kg per Reciprocal Agreement between Earth and the Moon

The initial mission costs for 200 mt to the Lunar surface and 900 mt to the Martian surface that emplaced the surface infrastructure necessary for subsequent sustainable crew arrivals were soon overshadowed by the triangle trade income that ensued due to extensive ISRU and shared IP between the Moon and Mars. Mars continued to ship to the Moon 50 mt of asteroid-mined phosphorus at a total cost of $500/kg that covered the mining costs as well as the $200/kg transportation cost. To balance the 81.6 ratio, Mars sent to the Earth-Orbiting Space Yard around 4000 mt, the mass of a GCR overcoat to cover with 3 meters of regolith a 6-m diameter by 10-m long cylindrical module, and lots of phosphorus. In return, Mars would receive around $2B trade credit which bought a lot of KP fission units, mobile NTAC power devices, Mars Air batteries, electronics, rovers, and mining equipment. Mars could lower its prices and still maintain a high trade surplus. The math was simple. Mars could also ship supplies to the Moon without using much propellant because of the favorable weak stability boundary and by timing deliveries from the asteroid while passing by Earth. To improve its margins on items shipped to Mars, the Earth-Orbiting Space Yard collected thousands of tons of space debris, consisting mostly of aluminum, that became the structures for the rovers, power units, asteroid miners, resources transport containers, and other items shipped to Mars and the Moon. Martian economists spent more time monitoring commodity prices on Earth and mining output fluctuations on the asteroids than calculating the trade balance with the Moon and Earth, an appealing luxury when exploiting abundance rather than managing scarcity.

Dorothy gives a tour of the colony identifying many technical, economic, social, cultural, political, organizational, and aesthetics of the Mars Colony.

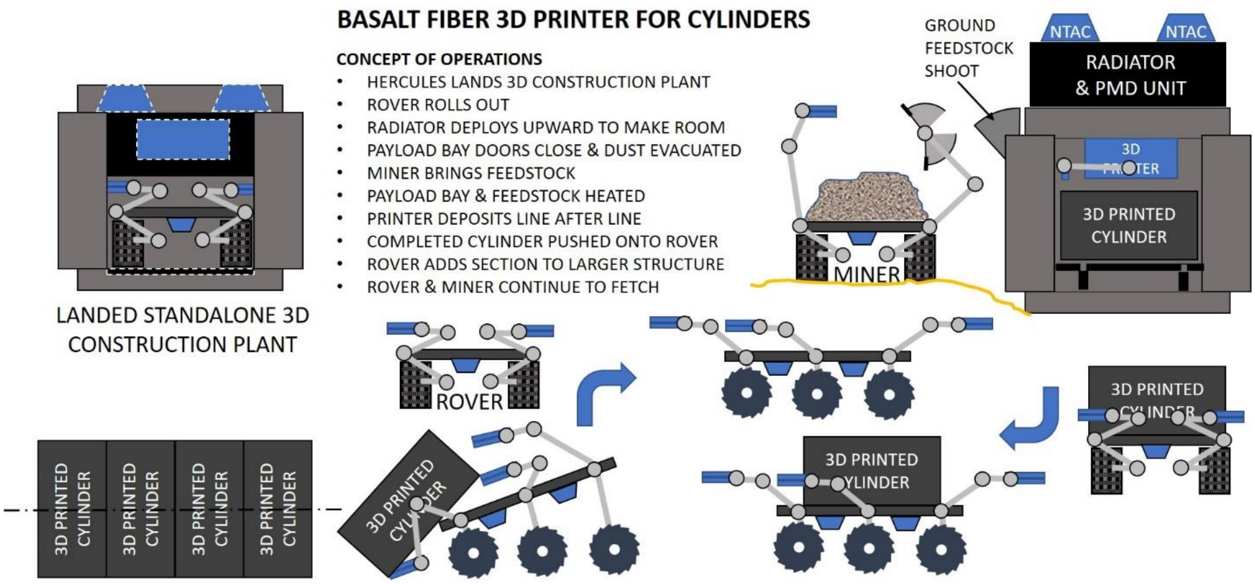
Dorothy awoke to the quiet hum of air flowing through the automatic vents into the main ducts above and below her bedroom. Her head still on her bed pillow, Dorothy looked through the low window in her bedroom to see twilight giving way to the dawn. She could not see the sky but could see the ground and the landscape that included mostly a small natural courtyard enclosed by the foot of a long cliff face that extended high into the orange-tinted Martian sky. She looked to see if the yard sign shaped like an ostrich with its head buried in the sand was still outside her window. It was placed there many years ago when she was in kindergarten as a reminder that a head hidden from view didn't necessarily mean that your body was too. The ostriches were made by the kindergarten children during their lesson on Galactic Cosmic Ray radiation. She wanted so much to go outside and touch it. But minors were not allowed outside except on emergency because suits do not have GCR shielding. She was one day away from her first trip outside. Today was her dress rehearsal for trying on EVA suits and walking through the operations of airlocks and pressurized rovers. She already passed the exams on Extra Vehicular Activities (EVAs). She reached down to check the small wearable radiometer on her chest. She smiled. All zeros still except for Safe Days which read "333". "I am no ostrich" she thought to herself. The thick regolith and some ice shielding prevented most GCR radiation from reaching the colonists. She remembered accelerator particle studies and harmful secondary neutron production in high Z materials. She remembered reading in middle school that 5 meters of regolith dropped the effective dose to 0.01 mSv/day and that 3 meters of regolith dropped the effective dose to 0.1 mSv/day. She did some simple math in her head and figured that her daily effective dose was somewhere between those 2 values. One day shy of one year old, her radiometer was the latest model, now made, except for the computer chip and battery from Earth, on Mars. The device tracked her dose and compared it to the proxy annual dose allowable that then calculated Safe Days remaining in Space this current birth year. "Any number above one the day before my birthday is a good thing," she thought to herself. Tomorrow, her new badge would read "355", representing Mars days in one Earth year. "Suits would be unmanageable if covered with meters thick material," she thought.

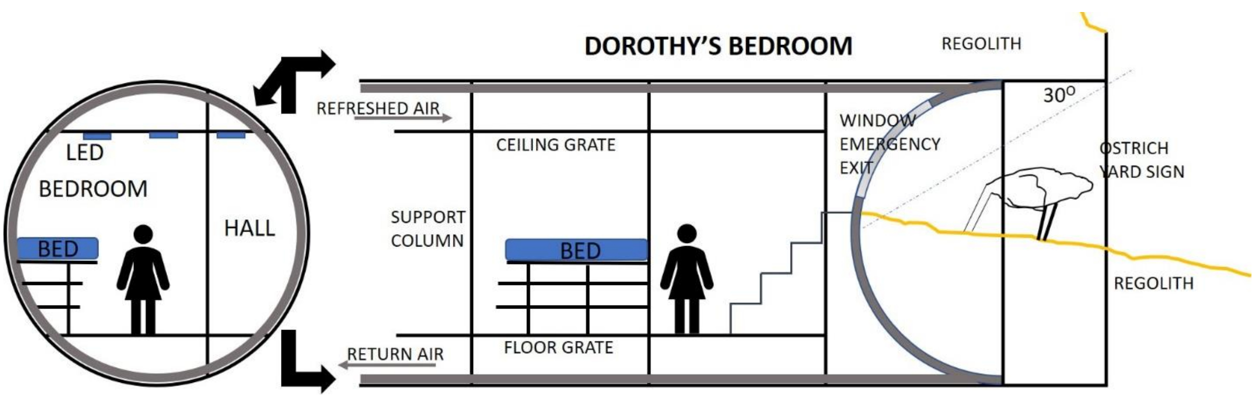
Dorothy's bedroom was the end of a 24-meter cylinder with a concave cap that included a glass window favoring the top of the cap. Columns made of basalt fiber were evenly spaced along the length of the cylinder's interior surface to prevent collapse of the cylinder in the unlikely event of sudden pressure loss. The floor was made of basalt grating covered with plastic panels. All items were made on planet including the spare parts used to maintain the zoned central heating and ventilation system that ran above the ceiling and beneath the flooring throughout the annex. Plastic parts like pumps and valves were easy to 3D print and swap out when necessary. An A.I. system monitored air pressure and temperature throughout the system to turn on and off compressors and fans and to open and close vents and baffles. The A.I. could predict when and where maintenance would be required next and order spare parts 3D printed and replaced routinely. The A.I. also inspected the worn parts and made design recommendations that were reviewed and certified by the master HVAC mechanic. She remembered learning about A.I. in fifth grade and how it was implemented across all domestic plumbing, mechanical, and electrical systems throughout the colony. 3D printed parts were cheap since plastic feedstock was produced on planet as part of the routine extensive ISRU suite that started with processing water and carbon dioxide to produce propellants, breathable air, and consumables.

She remembered the book report that she completed in sixth grade on "The Way Things Are on Mars". She accessed digital copies of papers by some original thinkers on Human-Mars Mission concepts like Zubrin, Aldrin, Cucinotta, Bushnell, Sanders, Metzger, Mueller, Strickland, Crossman, Troutman, Komar, Moses, Singleterry, and many others, to design many of the structures and equipment used on Mars. She learned reading Slaba's papers that the Mars atmosphere and terrain were sufficient to shield against GRC radiation up to about 30 degrees from the horizon in many places. That knowledge allowed for "really cool" architectural designs of structures that allowed natural light to enter from the horizon and reflected throughout the interior while supporting thick roofs and walls that shielded against GCR, micrometeoroids, freezing temperatures, and low pressures outside. Several meters of regolith covered the exterior of her bedroom. She enjoyed looking out her bedroom window, her main connection with the outside.

She remembered learning about Mars regolith in elementary school. The most abundant chemical elements in the Martian crust were silicon, oxygen, iron, magnesium, aluminum, calcium, and potassium, major components of the minerals comprising igneous rocks. The elements titanium, chromium, manganese, sulfur, phosphorus, sodium, and chlorine were less abundant. Hydrogen was present as water (H2O) ice and in hydrated minerals. Carbon was present as carbon dioxide (CO2) in the atmosphere, sometimes as dry ice at the poles, also stored in carbonates. Molecular nitrogen (N2) made up 2.7 percent of the atmosphere. Organic compounds are absent except for a trace of methane detected in the atmosphere on occasion. Basalt seemed everywhere. She could see lots of it from her bedroom window.

Dorothy ran her hand along the glass window and then the wall as far as she could reach. The window was colder than the wall and served as an emergency exit. An emergency EVA suit was hanging on the back of her door which was also printed on Mars. The window was made from Mars silica using glass manufacturing techniques similar to those on Earth. "To Earth," she thought and smiled. "Maybe someday," she said to herself. She remembered from middle school that the energy required for converting basalt to basalt fiber was 5 KWh/kg compared to 15 KWh/kg for making carbon steel products on Earth. KP and NTAC units could easily keep up with that demand. The number of units was based on how quickly the structures needed to be built. On Mars, robots could work night and day all year long, rarely breaking for a severe dust storm. The cylindrical structure was made of 25-micron basalt fibers combined into a single 500-micron stream using a 3D printer made of Tungsten-Carbide. Each 3-meter section of 5-meter diameter cylinder began with a printed 500-micron thick circle of basalt fiber around a 2-centimeter diameter stick frame that set the location of the floor, hallway, and ceiling. This frame prevented collapse of the cylinder during construction activities and in the event of a pressure loss after construction was completed. In a large box kept warm by the hot basalt extrusion process, the 3D printer deposited consecutive circular layers of basalt fiber until the cylinder stood 3 meters tall, weighing around 60 kilograms. The last printer pass created an inner edge that would fit inside the adjacent cylinder. Her bedroom used 3 cylinder sections erected by rovers with tilt beds and mechanical arms that extracted each 3D-printed cylinder horizontally from the printer box, drove it over to the end of the previously erected cylinder, tilted and pressed the cylinder section into proper alignment with the cylinder run, then returned to the printer to wait for the next cylinder. Afterwards, a separate 3D printer deposited 5 inches of plastic insulation inside the cylinder that also sealed the joints. A small crew oversaw the entire robust process. At the end of each cylinder run was a concave cap just like her bedroom. The other end of the 24-meter cylinder connected with a center hallway. In all, there were 40 of the 24-meter long cylinders in this cluster, housing over 200 crew plus their facilities. There were six of these clusters built interconnected into one large Annex 1.





The joint between the window and the wall consisted of a metal strip with bolts and seals. The seals were made of polylactide (PLA) thermoplastic and the metal made of basalt fiber, all 3D printed on Mars. The PLA plastic originated from several plant species grown in the greenhouses, and basalt could be found everywhere on Mars. She had learned earlier in high school that energy determined what was built and used on Mars. She earned merit badges in all 6 ISRU areas: 1) Prospecting; 2) Extraction; 3) Processing; 4) Construction; 5) Manufacturing; and 6) Energy. Her favorite was construction. She also excelled in organic agriculture, resource mining, and orbital mechanics.

She was fascinated with how plastic feedstock and propellants were created by combining water and carbon dioxide, and that in many cases heat was created. Nearly every plastic available on Earth could be made from resources on Mars. On Earth, most plastics are hydrocarbon polymers, made from water and air using electricity. She remembered that the first step to making plastics on Mars is to make hydrogen and carbon monoxide gas. The majority of energy consumed while making plastics occurred during hydrogen production via typical water electrolysis across a proton transport membrane, $H_2O \rightarrow 2\ H_2 + O_2$. Carbon Monoxide is produced by the process called Reverse Water Gas Shift (RWGS): $CO_2 + H_2 \rightarrow CO + H_2O$. CO_2 gas could be used in a Sabatier reactor to make methane CH_4 to fuel rockets, rovers, and hoppers: $CO_2 + H_2 \rightarrow CH_4 + 2\ H_2O$. An alternate method used RWGS with electrolysis: $3\ CO_2 + 6\ H_2 \rightarrow CH_4 + 4\ H_2O + 2\ CO$. Using a Fischer-Tropsche process, hydrogen and carbon monoxide can be reacted in the presence of an iron catalyst to form Ethylene C_2H_4: $2\ CO + 4\ H_2 \rightarrow C_2H_4 + 2\ H_2O$. Ethylene served as a fuel as well as the starting point to manufacture almost all other plastics. Adding fluorine and chlorine from apatite made the plastics extremely strong, durable at low Martian temperatures, immune to acids and alkali, and highly resistant to strong ultraviolet light.

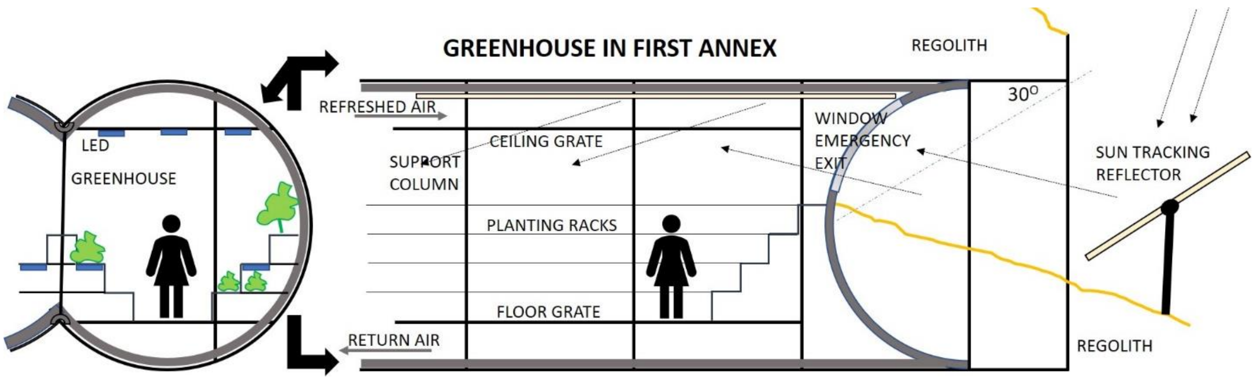
Dorothy walked across her room and opened the drawers to her dresser. That too was made on Mars using plastics. Just about everything in her room was made on Mars, including her garments and toiletries. During her junior year, she programmed a 3D printer to print thin fabric films and demonstrate their uses. She printed a wearable programmable Safe Days radiator badge chassis that only required a computer chip and a battery, which she borrowed from a prior badge to demonstrate feasibility of her new prototype. She also printed 100-feet of toilet paper and a multicolor reusable dish towel. She won first place by printing the dish towel with multiple colors and material types synthesized from repurposed materials. And of course, she also won first prize for printing toilet paper. She received 100 orders of toilet paper that day. Her blue ribbons for first place were also printed on Mars using PLA plastic. Her cloth printing in multicolor was soon implemented for printing merit badges and other clothes. She grabbed her tooth brush, hair brush, and change of clothes, put on her slippers, all made on Mars, and headed to the ladies' shower room. Ten minutes later, she returned to her room to drop off her PJs, toiletries, and to change shoes. She was ready to head to breakfast in the dining hall in her annex.

Her bedroom was in the oldest annex, built when Dorothy's father Chris led the first astronauts to Mars. Dorothy's mother Colleen commanded a later crew. They married about 20 years ago on Mars. The ceremony was held outside wearing EVA suits. It was the first wedding held on Mars. At that time, there were about 100 astronauts on Mars. Now, there are 1000. There have been many weddings and births since then. Dorothy was the first girl born on Mars, but she was not the first child born on Mars. Her high social status allowed her access to many areas of the city, but not outside. She planned to put that access to good use today.

Dorothy entered the dining hall that was much wider than 5-meters. Several 5-meter diameter cylinder tubes had been laid side by side in parallel and a portion of their sides cut open, and the exposed edges of the walls covered by smaller quarter-arc cylinders that were supported by a line of columns to create an open floor plan. The open area was required to allow room for tables and the food processors. Its construction included many of the same features found in the structure of her bedroom including plastic insulation and several meters of regolith overburden for protection.

Dorothy walked over to the computer touchpad tablet setting on an open table. The tables were picnic style made of plastics. The computer tablet was assembled on planet using many parts made on planet. It was connected to a Wi-Fi system of similar origin. Dorothy tapped on the Breakfast icon. Today's selections included cereal, protein-meal, and juice. She selected one of each. Before she got to the receiving counter, a tray emerged with the items clearly displayed on them. "A.I. at work," she thought to herself as she sat down next to the computer tablet. In the bowl were cereal flakes made from cassava, a plant that offered versatility of uses besides food including PLA plastic feedstock for 3D printing seals, gaskets, filters, and "tea" bags. Freeze-dried fruit pieces could be seen above the soy milk as well. The A.I. had steamed them before placing them in the bowl and adding milk. Many items were frozen here. Finding freezing temperatures on planet was quite easy and required no mechanical work, only shade. The protein-meal was a blend of cassava, mushrooms, and insects today. She remembered learning all about the Martian food cycle in elementary school. The colonists had grown tired of potatoes, kale, and mealworms for a while. Prior to the expiration date, Meals Ready to Eat (MER) packaging was sometimes seen in the recycled trash cans. There were several forms of protein available from the grow houses, but today only insects were on the menu. In the cup was a juice, a blended mixture of whatever fruit was processed recently. Having food allergies did not bode well on Mars. If you developed allergies, then your options were very limited here. Returning to Earth might be a strong consideration. After a few bites with her combinational spoon-fork ("spork") utensil, she wanted to know when fresh fruit might return to the menu. She backed out of the Breakfast icon to the main screen and clicked on the Harvest icon. The next level revealed several icons to choose from Most Popular to Food Groups to All Foods that could be queried based on a variety of search terms. She clicked on Soon to Harvest. Strawberries was top of the list. She needed to look no further. She hurried up her breakfast so that she could get to the greenhouse to watch the harvest. Once done, she placed the tray, bowl, cup, and utensil in the dishwasher. Everything she placed in the dishwasher was made from plastic. Most plastics would easily survive the dishwasher, but some PLA plastics were designed to be dissolved by the hot water in the dishwasher or biodegrade quickly in the compost. Rarely did any food go uneaten. On those rare occasions, the uneaten food was either taken with the colleague to be eaten later or discarded into the bucket next to the dishwasher. The contents of that bucket were deposited into the compost facility several times per day. Quite a few hyper-thermophilic compost reactors waited for their periodic resupply of fresh waste from the kitchen and sanitation collection sites. Once ready for the greenhouse, the compost was enriched with nitrogen if heading to the grow room or enriched with phosphorus if heading to the bloom room to boost edible yields. "Appetite craves Apatite," she snickered to herself. On Earth, high microbial activity in the greenhouse soils and compost tea cisterns is ensured by using aged-fired tree bark. On the Moon and Mars, the tree bark is substituted with porous basalt ore that is aged in the compost facility. Mars' earliest microbe cultures were shipped fast transit from the Moon.

The colony used hyper-thermophilic aerobic composting bacterial ecology for increasing the effectiveness of processing human metabolic waste and inedible biomass into fertilizer for the greenhouses. This microbial technology was well established for the purpose of processing sewage and waste materials for communities on Earth and on the Moon. Metabolic heat released during bacterial fermentation raised the processing temperature to 80–100 °C to support hyper-thermophilic bacteria. The hyper-thermophilic system decomposed wastes in a reasonably short period of time while providing high quality fertilizer as an end-product. High quality compost was one key element in creating a healthy regenerative food production system. The soil microbial ecology with the addition of high-quality compost and the basalt ore continued to improve plant growth. The high processing temperature sterilized the pathogenic organisms through the fermentation process and secured the hygienic safety of the system. The greenhouses utilized solar energy received on the Martian surface as well as low voltage wavelength-specific LED lights for supplying energy for photosynthesis. Within each greenhouse, subsurface water and atmospheric carbon dioxide are mined for quick use in the plant cultivation system. The parts of the plants that were not eaten were recycled or became materials for construction and manufacturing. The symbiotic combination of hyper-thermophilic aerobic composting, plant growth, and human biology would not achieve the high yields necessary to support the large colony if it didn't utilize in-situ natural local resources available on Mars. This is the key reason that greenhouses on Mars produced far higher yields than greenhouses in Space and on the Moon, and in many cases, even those on Earth now. The greenhouse produced more than the 2 kg per day of food required by the 1000 colonists. Much was processed, packaged, and stored on Mars. Mars had plenty of natural cold storage at below freezing temperatures.



Dorothy enters the greenhouse closest to her annex. It stems from the first greenhouse on Mars. The greenhouse layout is similar to the open layout of the dining hall. The entire greenhouse, except for the capped end of each cylinder, was covered with several meters of regolith for GCR shielding and protection from other environmental conditions outside. Light coming off the solar concentrators located just outside each end cap entered the windows on the concave ends and reflected upwards along the reflective silica tiled reflective interior of the cylinders. The length of each cylindrical tube was sized based on reflectivity of the natural light within the tube. Basalt fiber columns from ceiling to floor protect against collapse. LED lights with both red and blue spectrum hang from the ceilings and from beneath each tray arranged in stair steps up the cylindrical wall about half way. She could smell the fresh microbial compost that just arrived from the compost facility. She inspected some of the plants that looked very healthy. The compost was excellent in modifying the Martian soils for agriculture. They were now growing trees in the taller annexes for increasing the supply of breathable oxygen and construction materials. Early on, NASA experimented with several varieties of lettuce, spinach, carrots, tomatoes, green onions, radishes, bell peppers, strawberries, fresh herbs, and cabbages. Other plants were added to the trials to accelerate Earth-independence. For carbohydrates, Bioengineering Project BioCassava Plus was modified for implementation in Lunar greenhouses to eliminate nearly all cyanogenic glycosides and fortification of vitamin A, iron, and protein. Synthetic biology led to new engineered plants with higher resistance to disease, more nutrient-packed foods with a longer shelf life, as well as foods tailored for specific uses including medicine. The taller plant types were placed on the top tray while the smaller plant types were placed lower. This greenhouse concept was developed over several years on the Lunar surface. The trays on one side are mostly freshwater hydroponics while the trays on the opposite side are mostly soil. Seeds are germinated in wet clothes made on planet using recycled leaves and transplanted to soil in growing cubes made of PLA plastics that dissolve over time. At the end of each season, the dying plants' foliage is processed into paper and cloth feedstock. Soaps, body wash, and toothpaste were produced from Soap Lilly and Soapwort, 2 species containing saponins. Dorothy already knew where to find the fresh strawberries. She could see several colleagues inspecting the trays as she approached that area of the greenhouse. Hearing her footsteps, the colleagues looked up and smiled upon recognizing Dorothy who was well known in the greenhouse. Dorothy had earned her master gardener badges online and then verified in the greenhouse during 2 growing seasons her understanding of organic agriculture and hydroponics by growing, well, strawberries. She was as much an expert on strawberries as any colonist. The greenhouse master Greg leaned over to Dorothy and whispered, "After the strawberry harvest, there's something new that I would like to show you. Arrived late yesterday." Orbital mechanics was one of the easiest courses to complete, she thought to herself. The lab for that course was basically to illustrate on a large poster up to 10 fast trajectories between Earth and Mars. The students had to sort out whether aerocapture or propulsion deceleration were required to achieve rendezvous with the Mars Orbiting Node (MON). She won the blue ribbon for creativity. She had yet to go to the Node but hoped to someday soon. Dorothy replied to Greg, "But, it's not time for a cargo delivery. The next cargo arrival is in seven months," she said. Greg smiled. "They were shipped on a small fast transit because of their nature." Dorothy got ready to ask which fast transit type, but Greg cut her off. "Meet me later Dorothy before dinner." Dorothy walked through the greenhouse identifying many plants including halophytes, soy, and fruit trees. Success converting Earth's wasteland into halophyte farms solved Earth's land, water, food, climate, and energy problems. Additional phytoremediation and synthetic biology studies produced tenacious halophytes that thrived in high concentrations of perchlorates breaking down the soil for terrestrial organic growth processes to take hold. Fruit trees continued to indicate successful organic methods. Synthetic biology was employed to boost plant yields, create new disease-resistant strains, enable on-demand printing of pharmaceuticals for battling extremophiles and other diseases. She exited the greenhouse but would return later to find Greg after she completed her prior commitments for today.

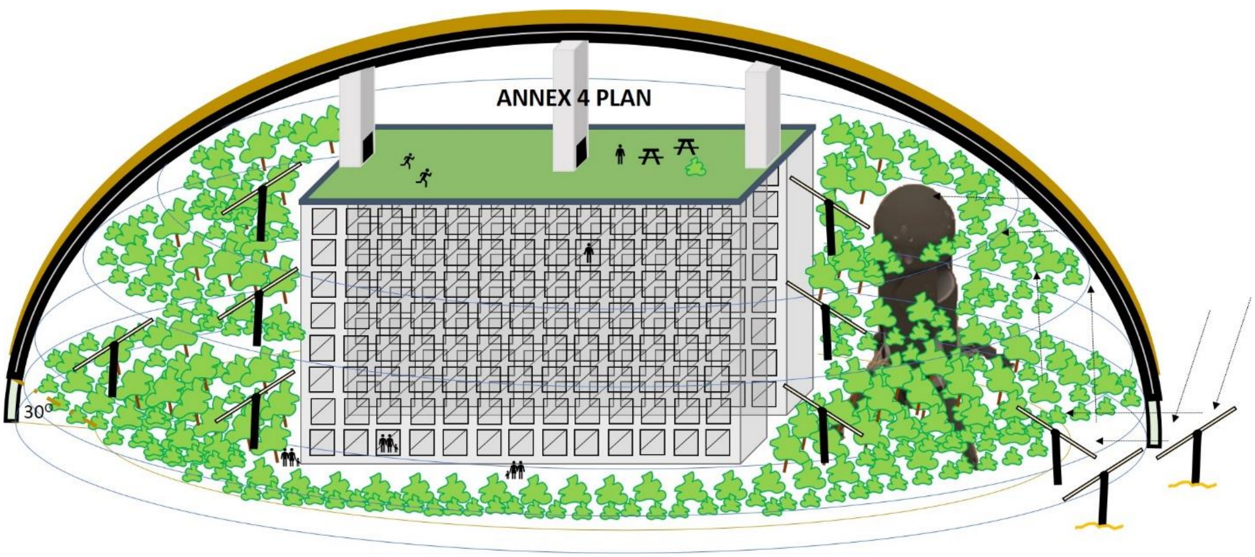
On her way to the EVA Suit Facility, Dorothy walks by 5 posters announcing the upcoming public Ministers' Briefings. She touched a poster and could easily tell that it was printed on Mars. Each poster summarized each Minister's presentation topics. **Trade & Treasury**: Earth had already depleted the resources in the dozen or so Easily Retrievable Objects and was consuming quickly all the phosphorus mined from asteroids by Mars. Earth was requesting additional asteroids be mined and their resources sent to Earth. Mining companies turned their attention to the Asteroid Belt beyond Mars. That would mean increased investment in Earth's science missions beyond just refueling in Mars orbit deep space satellites heading beyond Mars, growing a stronger collaboration with Earth and the Moon that enjoyed their ongoing trade with Mars. **Health & Safety:** More efficient solar power farms for reducing orders for KP units; disposal procedures for aging KP units; no storage of spent rods would be allowed on Mars. Higher efficient solar power meant adopting many of the materials used on Earth such as indium and gallium and boron nitride. Boron could be mined on Mars. Other materials would need to come from asteroids. Plant and animal natural acclimation study. "What animal?" she said out loud. **Arts, Sports & Entertainment:** Due to their long trails and distances from the main colony, outside sport venues such as canyon jumping and Planitia hopping required dedicated power, cameras, broadband communications, pressurized rover trails, and some emergency facilities. **Governance:** Add Federal-like overlay to handle the increased international collaboration and obtain a seat on Earth's UN Council. Host a flag design competition. **Education, Science, and Intellect:** Increased interplanetary broadband for data sharing with Earth and the Moon; more lab space for K-4 since younger students were well ahead of expectations, thanks mainly to mentoring by older siblings during after school study halls; R&D budget for more aquaculture trials for expanding the food sources; increase in ink colors requiring a larger variety of flowering plants; improvements in cloth printing for finer weaves and more material options; R&D budget for prospecting and mining in the asteroid belt beyond Mars.

As she walks on, she contemplates how she would vote. These topics came up regularly during dinner with her parents and sometimes during lunches with classmates. Government class was a required every year for children and adults so that they stayed abreast of the issues affecting Mars. Unlike Earth, the issues on Mars were not that old and the length of experiences were less than one generation old. There were no grandparents on Mars, except for those old enough to have grandchildren back on Earth. Only two generation were represented on Mars, and they shared much of the same experience base. There were very few new technologies or ways of life created over that time period except for A.I. and some robotic capabilities. But everyone on Mars knew how to work with A.I., robotics, and computers. Everyone agreed with the Ministers' proposals. The debates usually were over funding priorities since not everything could be addressed near-term with current resources including people. She made a mental note of her top 5 funding priorities. After all, she would be legal to vote after her birthday tomorrow.

Dorothy arrives at the EVA Suit Facility. She meets with the facility head who helps her try on suits. Afterwards, she is walked through the airlock procedures before putting on her suit. Then, she puts on her suit and joins the facility head in the airlock. She goes through a mock rehearsal of activating each control. "Is this new?" she asked. "Yes," said the master. "It's a new design that we made here." After three mock rehearsals, they exited the airlock and removed their suits. "Your EVA Card will be printed tonight," said the master. Dorothy thanked the master and then walked toward the EVA Maintenance Facility in the adjacent compartment of the annex.

Dorothy enters the EVA Maintenance Facility. She walks through the repair area noticing the 3D printers that print spare parts. ABS, TPU, PLA plastics. Basalt, silica, and alumina. She then looks through the large window into the maintenance bay where vehicles are brought inside for maintenance and refueling. To enter there requires a special vehicle maintenance EVA card, which she cannot earn until passing several tests. Workers are wearing lightly pressurized garments that provide safety measures from sudden decompression and dust. She can hear dust collection system hissing through the glass as it replenished air into the maintenance bay. Heat from the printers and the hydrocarbon plants next door were circulated into the maintenance facility. She remembered during middle-school tours and labs how warm it was in here. She realizes it's time for lunch.

Dorothy enters the base of the cliff heading to the EVA Control Room, through the vacated main lava tube that leads into a series of tubular off-shoots that eventually leads her to a high scenic vantage point that overlooks the entire settlement. The main chamber now serves as the Launch & Landing Control Room and Colony Watch Tower. She can remember several renovations over the years as the colony grew. She has always known it as an enclosed conditioned space. In the earliest days, she remembered some older guys talking about "drywall", something used on Earth. She reached up and felt the wall. It felt much like the walls in her bedroom. In this case, it looked like a thick plastic layer painted onto the cavern walls. She heard that this was added to hold air pressure after the openings to the outside were capped. She pulls out the snacks and small lunch that she brought with her. While eating, she looks out the main control room window overlooking Subtle Ridge. Off to the far left is the KP fission farm and just before its berm enclosure are the Rodwells over top the ice lake. She cannot see the water lines and power lines but she can tell where trenches were filled in. Trenches run from the Rodwells to water treatment facilities along the row of greenhouses. Just to the left of "greenhouse row" is the launch and landing pad with a blast berm. She can see the basalt fiber "rugs" printed on the pad to prevent the creation of ejecta by the rocket plumes during launch and landing. Trenches run between the KP units and PMD boxes, then continue from there to the annexes. The underground cables were made on planet from aluminum and coated in polyethylene insulation. Just below her location, she can see her bedroom in the cluster of Annex 1. Closer to the launch pad is the EVA Suit and Maintenance Facilities where she was earlier. Heading outward from the EVA Facilities toward the horizon are the four rows of solar arrays over top buried clusters making up Annex 1's greenhouses, crew quarters, and facilities for over 1000 colonists. To the right of Annex 1 are the pride and joy of Subtle Ridge. Resembling a tortoise shell, Annexes 2 and 3 stand tall in plain view. Underground tunnels connected them to the older buildings. Smaller than Annex 3, Annex 2 served as the pilot project to demonstrate that the challenging construction project could be conducted in a timely manner using existing crew, A.I., long-arm surface manipulation systems modified with 3D printers, and other autonomous logistics. Annex 2 serves as the sports complex, arts center, and museum. It took several years to build, requiring an additional KP farm to the far right which was now being tapped to construct Annex 4. Standing nearly 30 meters tall and nearly 100 meters across, Annex 3 was much taller than Annex 2 and housed many integrated facilities. The larger Annex 3 was laid out much like the passenger cabins and common areas of a multi-deck seafaring cruise ship that she saw online while studying Earth's oceans. The cabins were arranged dorm style with shared restrooms within each cluster. The entire structure was 3D printed with basalt fiber using robots and some astronaut oversight via EVAs. Construction was completed in under one synodic period. The plans she had seen for Annex 4 showed more Earth-like structures to accelerate acclimation of the "incoming Earthlings" she thought to herself, with a smile.



The thickness of the roof shell was around 3 meters with a thin pocket of air to create a double hull to reduce temperature transmission from outside to inside surfaces. For added structural stability, a thin wall of printed basalt fiber connected the two hull layers and extended into the sky another meter to hold regolith on the roof for increased shielding. Much of the regolith was replenished during an occasional dust storm. Three meters thick polyethylene layer is printed onto the interior side of the double hull for GCR shielding and thermal protection. Robotic rovers moved regolith around as needed to maintain depth. Vertical construction like this would enable the colony to grow much faster since multi-story habitats could be placed under one large structure like this. The lower edge of the tortoise shell was constructed of thick glass windows between thick basalt fiber columns to allow natural light into the annex. Solar collectors could be seen around the perimeter. Where light shown through the glass, greenhouses could be seen from the control room. She grabbed the tablet on the control room desk and clicked on Maps. She then clicked on Annex 3. The greenhouse extended around the circumference of the entire shell. Interior to the greenhouses were row after row circumferentially of thick structural walls containing cubbies from floor to ceiling that resembled a wasp nest. The cubbies served as crew quarters and offices. Floor after floor of mesh platforms, landings, and staircases printed with basalt fiber ran between the walls for access to the cubbies and to serve as common spaces. In the basement were labs and schools and the six tunnel entrances. On the first floor in the center of the building was a large mezzanine that extended up to the ceiling. Mesh landings and staircases ran along the perimeter of each of the eight levels. Hanging planters held vined plants that intertwined with the railing along the platforms. LED lighting hung from the underside of the mesh platforms. It was a beautiful building. The first floor served as a main dining hall. A waterfall in the center played a soft melody of splashes all day long. How inviting! But not today. This is the last item on her list for tomorrow's preparations. She glanced further to the right to see the solar power farm and beyond the solar farm the second reusable lander landing and launch pad.

On the way to the greenhouse to meet Greg, she takes a quick detour by Annex 2. She first enters the museum with high ceilings, about 10 meters above the floor, so that the first exploration systems can be fully deployed for show. She walked among the items, seeing the first Rodwell integrated inside a payload bay section of an earlier lander. It stood about 6 meters tall. Similarly, the first KP unit had been integrated into a payload bay of an earlier lander. Its fission core had been removed. Its radiator fanned overhead about 4 meters above the floor. The payload bay of that lander could be flown off the bottom stage of the lander after initial landing to a location nearby. The Rodwell had been flown over to the ice pack. The KP unit was flown over to what is now the KP farm in the distance. Similarly, ISRU equipment, habitat, and pressurized rover were deployed. Since those days, upgrades led to reusable landers and other surface systems that allowed better repairability and spare parts to be made on planet such as rocket nozzles, thermal protection coatings, and plastic tires and gears. Standing nearly 20 meters tall, the first reusable lander stood inside Annex 4 that was currently under construction. Covered with old inflatable aeroshell fabric for dust protection, the reusable lander was moved to its display location in upright position using several pallet rovers. She pulled up the Annex 4 Plans on a tablet to see how magnificent the lander would look as the center piece. Dorothy walked to the sports section of Annex 2. The first inclination when astronauts arrived was to see how high they could jump. It became the fascination of the colony. So, they modified a few Earth sports to be played on Mars. She looked up and saw several basketball hoops with large backboards installed about 7 meters above the floor. On Mars, one didn't need to dribble the ball between ends of the court. The lighter gravity here made it possible to shoot the ball from the far end of the short court. Dunking the ball was still the favorite. Slam dunk contests took on a whole new perspective on Mars. Many wanted to take the sports outside and to add some track and field activities such as long jump and high jump. There was even talk of adding Canyon Jumping with unpressurized rovers and Planitia Hopping with ISRU-refueled jetpacks as annual competitions. She noticed the time.

She returns to the greenhouse to find Greg standing by a new hydroponics tank. She could smell the briny water immediately. She was an expert on Martian hydroponic systems. Freshwater aquacultures of plants and loach fish had been very successful on Mars, but they required considerable oversight. Countless hours were spent removing brine from their water. Sodium was managed by algae, sodium tolerant halophytes, reverse osmosis, and electrodialysis. What Greg was about to show her would blow all that away. "Look inside the bag setting in the tank," says Greg. "Seed oysters?" exclaimed Dorothy. "Yes," said Greg, "but these are not to eat." "Then why?" asked Dorothy. "Nature's most perfect water purification system," replied Greg. "These oysters are very tolerant of salinity levels and expected to do well in briny Mars water," said Greg. "They have had excellent success growing polyploidy oysters on the Moon," said Greg. "So, that's why we've been sending brine to the Moon all these years," said Dorothy. On Earth, oyster larvae generally reach spawning adult size in 18 months. Hatchery studies of triploids on the Moon were cutting that growth time by 40% to achieve a substantial crop routinely. "Rich tourists love eating oysters on the Moon," said Greg. "Is this the animal intended for the natural acclimation study?" asked Dorothy. "You read the poster," said Greg. "If approved, these hydroponic bays will be installed in that spare airlock. These halophytes will go in the top bays and the oysters in the bottom bays," explains Greg. "How are oysters going to survive outdoors here?" asked Dorothy. "Pressure at 10 meters water depth here is about 40% Earth's atmospheric pressure at its sea level," explains Greg. "Of course, hydrostatic pressure to simulate Earth conditions," replied Dorothy. Greg explains the rationale behind COSPAR's approval of oyster filtration and asks Dorothy to help him develop the oyster growing best practices through trial and error growth testing, a three-year long study at least. They would first need to perfect spawning. They would build upon the successes of hydroponic experiences to aquaculture freshwater loach fish and some algae species for nearly 2 decades on Mars. Once the processes were well understood, then they would implement A.I. to conduct many of the daily chores. Dorothy agreed to discuss this opportunity with her parents. She returns to her bedroom to wait for her parents' call for dinner.

Her dinner consists of some special food items. Clearly, her parents had visited Greg earlier today. "These oysters you can eat," laughed her mom. They discussed Greg's research plans with oysters and agreed that Dorothy would be perfect for that brine species program. Out came the cake. "Isn't that for tomorrow?" asked Dorothy. "Check the time," said her mom. "It's after midnight," said Dorothy. "Happy birthday," said her dad. The candles were made on Mars from a mixture of polyethylene and wax from Brazilian Feather palms and Candelilla shrubs grafted into hardy Cassava roots. After cake, it was time to open presents, but she saw none. Her parents asked her to join them in 30 minutes at the EVA Suit Facility to see her presents. When she arrived, her parents were already suited up except for their helmets. "Here's your first present," said her mom. Dorothy unwrapped it to find her newly issued EVA Card. "Get suited," said her dad. They all smiled. "We're going outside tonight?" she asked. "You could say that," replied her mom. Dorothy swipes her EVA Card first to enter the airlock. They perform a final check their suits. All good. Dorothy works the airlock controls under the watchful eyes of her parents. Soon they're outside. "Where to?" Dorothy asks as her dad heads to the pressurized rover. They hop on. The rover heads to the launch pad. Dorothy is excited. She gets a special treat, a flight to Low Mars Orbit. The launch is beyond belief and much smoother than she expected. She continues to look out the window. In orbit, she sees the Orbiting Node ahead. Shaped like a shower cap with the opening facing the planet, the GCR Shielding cocoon protected the crew from harmful radiation while permitting easy docking from below. Other docking ports were provided around the perimeter of the cocoon as well. "Take the controls," says mom. "Are you serious?" "Yes," said dad. "I will take over if you get off course." She eases the ascent vehicle toward the docking ring. "Great job. I'll take it from here," says dad as he engages the automatic docking. They laugh. Soon, they're docked. Microgravity is new to her. "Are you okay," asked her dad. "Yes, I think I got this," replied Dorothy. Three crew were staffing the Orbiting Node tonight. One gave her a tour of some basic manufacturing that occurs there for goods being sent to Earth-Lunar Orbit. The items manufactured in LMO include propellants, interplanetary spacecraft spare parts, radiation shields, and thermal protection coatings that produce some harmful gases that are unwanted on the planet. He described how a convoy of cargo ships arrive during every synodic period evenly spaced on intervals to allow time to dock, unload, and relocate to another port-lock. He mentioned receiving a special shipment on a fast transit the night before, but he was not allowed to state its contents. She smiled and shared with him how delicious the oysters tasted. He showed Dorothy the manifest listing the asteroid deliveries last month that were processed. He also showed where items in her vehicle are heading to the asteroid to help convert it to an Aldrin cycler. Her thesis on predicting which of the 4 mined asteroids could become the first cycler did not consider this asteroid since it wasn't among the 4 mined at that time. "We discovered an asteroid with a large more accessible supply of phosphorus," said her mom. "Are they renovating it like the cavern that's now the Control Room?" asked Dorothy. Her mom nodded and smiled. Each resource packet was pushed away from the asteroid with the canon gun at specifics times to shape the asteroid's orbit. A.I calculated the orbits, delta v, the mass to load on the canon, and canon's spring force. Deliveries arrived accordingly and often. The now lighter asteroid's orbit was now on a cycler pathway between the Earth and Mars. The Space Force would move in once the artificial gravity gym was completed for musculoskeletal conditioning and Spaceflight Associated Neuro-ocular Syndrome relief. Its axial motor bearing set would be delivered during the asteroid's next pass by Earth using an Aldrin's hyperbolic rendezvous. The Space Force officer floats over with Dorothy's dad. He shows her the import and export logs of items that pass through the Orbiting Node. The items going to the asteroid are included but don't show up in the Replenish Trade column since they are not intended to ever go to the Moon or Earth. "Are we in a surplus or deficit trade situation?" asked Dorothy. "Strong surplus," replied the officer. "Because of the 81.6 ratio rule?" asked Dorothy. "Yes indeed," replied the officer. "But refueling science missions from Earth heading to the outer solar system continue to increase year after year and are expected to continue," said the officer. "Why?" asked Dorothy. "Space Steading Timeshares in the Earth-Moon system is driving higher demand on asteroid resources for GCR shielding materials, phosphorus, water, and other resources," said the officer. "Why timeshares?" asked Dorothy. "GCR limits still dictate the number of safe days a person may spend in Space even with shielding," said the officer. "Safe days in Space are rented. Timeshares would not be possible without GCR shielding materials mined from asteroids," said the officer. "Large mass is still the only way to shield against GCR," said the officer. "Shielding would make our suits too heavy to wear." Dorothy stared at her suit. Her mom interrupted Dorothy's stare, "Ready to head home?"

Dorothy and her parents suited back up and entered the reusable lander they rode up on. It detaches from the Orbiting Node. They make a couple of passes around Mars, seeing Deimos and Phobos overhead. "What's that?" points Dorothy to a mildly lit large structure below on Mars. "That's New Scape," said her mom. "Another settlement began last synodic period. A crew of 5 landed there armed with all the latest technologies and are carving a new city out of the wilderness," said her dad. "That's remarkable. Don't you mean a crew of 50?" asked Dorothy. "Those new methods developed on the Moon and recently implemented here are being adopted on Earth to renovate many cities with antiquated infrastructure," said her dad. "The repurposing methods learned here have led to higher efficiencies of materials reuse on Earth. And, as we learn more about how to do that here, we may be able to go further into our solar system," explained her dad. "You mean Titan?" asked Dorothy. "Yes, Titan is one of many places to consider." The benign aerodynamic portion of the reentry ends. Komar showed years ago during his reusable lander studies that entries from Low Mars Orbit barely stressed the lander and its Thermal Protection System. "There's our place, Subtle Ridge," pointed her mom. Dorothy learned in middle school that the Space Shuttle many years ago on Earth demonstrated time after time the capability to land crew and cargo with winged entry and without propellant. Longitudinal protrusions starting near the nose and becoming wider near the tail helped maneuver their lander toward the landing pad. Before reaching the pad, the lander fired its nose and tail thrusters, pitched up, and set down on its tail. This vertical landing mode resulted in the quickest turnaround for the next launch and diminished any need for a long landing strip. They exit the lander and walk over to the EVA Annex. They enter the airlock, walk through the Return procedures, then enter the EVA facility with clean suits. Dorothy places her suit with her parents in their locker. “Thanks Mom and Dad for the best birthday present ever!” Dorothy paused, looked back into the locker, and spoke, “I may know a way to shield the suits from GCR radiation.” She explained her idea. Dorothy dad replies, “That might work, and everything you need is right here on Mars. Human spaceflight everywhere will benefit enormously if that works. I suppose that you will be filing another patent claim soon. You have become quite the Martian, young lady! Everyone is so proud of you!” Tears of joy begin to form in Dorothy’s eyes as she sees her dad’s eyes tear up. “You’ve had a very long day,” said her mom. “Ready for bed?” Dorothy nodded, hugged her parents. When she reached her bedroom, she laid down fully clothed. She tried to fall asleep, but the excitement of the day still lingered. Earlier tonight, she gained a grander perspective of the importance of every course, every lab, every test taken during her entire life on Mars. She remembered Ecology & Mining that included Greenhouses and 3D Printing; Government that included Space Law; Economics & International Trade; Geography including Inner and Outer Solar System and how they needed to know at any moment the location of all planets, moons, and the asteroids being mined by Mars; 4 languages including a new Martian dialect that needed lots of work; and applied mathematics for orbital mechanics to explore possible transfers between Earth and Mars and engineered systems of all types. She thought about all her book reports, special projects, merit badges, and blue ribbons. She couldn’t wait to make even greater contributions now that everything she learned had merged into a far keener awareness, and she now had access to the outdoors to test a new suit design. She was truly the poster child for humanity’s success in becoming a two-planet species. She wanted to share it with anyone anywhere, especially on the only World she has ever known: Mars.