K-Town: A Thousand-Person Colony on Mars

March 31, 2049

Jeff Greenblatt[1] and Akhil Rao[2]
[1]Emerging Futures, LLC, Berkeley, CA USA [2]Middlebury College, Middlebury, VT, USA (pending)

Submitted to The Mars Society's 2019 Mars Colony Prize

1. Overview

Welcome to K-Town, the largest human settlement on Mars! It is located at 47°N, 274°E in a flat region of western Tempe Terra adjacent to a number of beautiful and scientifically interesting natural features. The town itself occupies 0.6 km^2, not including its solar array or various surface mining operations. It is also sufficiently far north to access large quantities of subsurface water that are available there. In the future, Mars may be terraformed, so K-Town was located at sufficiently high altitude to avoid being flooded if Mars' ice caps were to melt. It is also adjacent to many interesting geologic features including numerous outflow channels from an ancient Mars ocean. About 800 km to the southwest lies Alba Mons, one of Mars' great volcanoes. Further south off the map is the Tharsis Rise, containing the three Tharsis Montes volcanoes and Valles Marineris, the "Grand Canyon" of Mars. See Fig. 1.

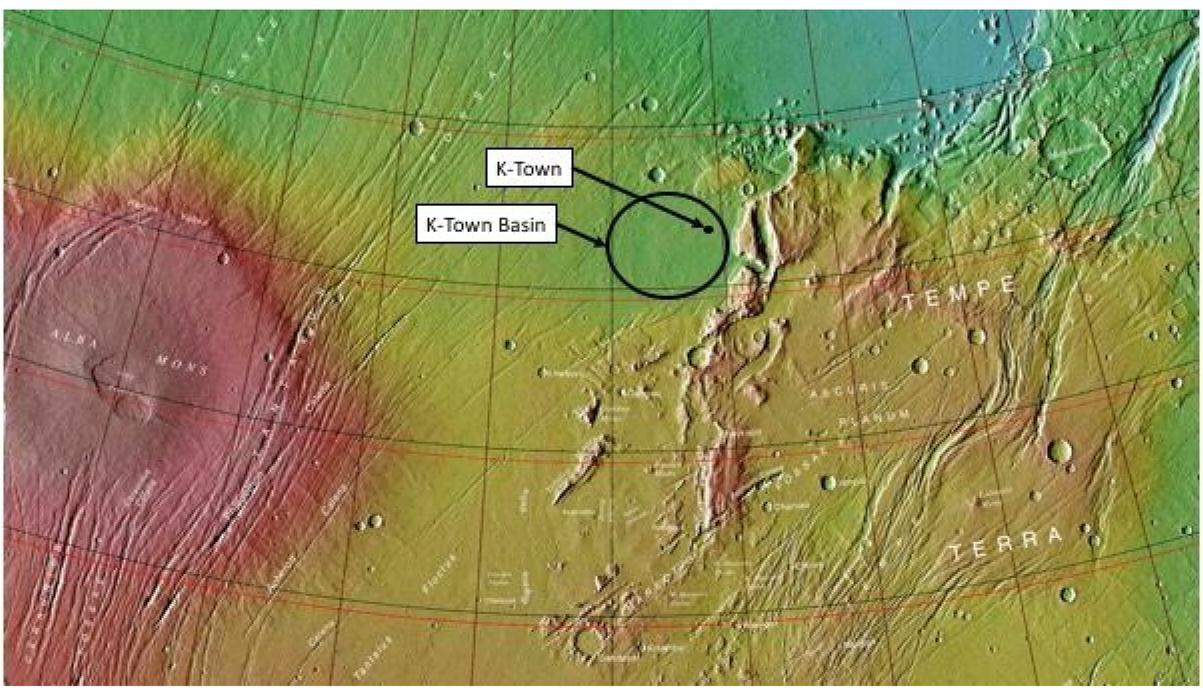

Fig. 1. Location of K-Town ar 47°N, 274°E within the Tempe Terra region. Source: [1]

K-Town is comprised of people with a wide variety of skills and backgrounds (see section 2), and herald from various corners of Earth; however, a few recent arrivals herald from K-Town itself—we will discuss the safety of giving birth on Mars below. In addition to a significant flux of tourists, young adults seeking work, and permanent retirees, several major corporations on Earth have recently started sending representatives to K-Town, often along with their families, to scout out new business opportunities and broker deals with other businesses already there. Companies in the Forbes Interglobal 2000 including

Amgen (biotech), ArcelorMittal (metals), AT&T (communications), Bank of China (finance), BASF (chemicals), BHP Billiton (mining), Caterpillar (heavy equipment), Heidelberg Cement, Hilton Hotels, LabCorp (medical), LG (appliances), Microsoft (software), Mitsubishi Electric, Nestle (food processing) and Waste Management have recently opened small offices in the commercial sector of K-Town.

So named because it recently passed the 1,000-person population threshold, K-Town may have to change its name again in the future, as its population continues to grow at about 7.1% per Earth year ("E-year"), or 13.7% per Mars year ("M-year"). K-Town is also not the only settlement on Mars, but these other pockets of humanity can hardly be called "towns" at this point, as they only consist of a handful of people living in the most basic life support accommodations, and heavily dependent on both K-Town as well as Earth for their continued existence. Scientific outposts, mining operations, and a few tourist attractions are scattered across the globe, with some accessible by Hyperloop spurs that have been built at private expense to allow for efficient transport of people and goods. Other locations, such as Hellas Planitia Outpost or South Pole Station, are still too far away and can only be reached via suborbital rocket "hop," and residents of K-Town almost never see people from those locations, as they tend to fly directly to or from Earth. Nonetheless, a nearly-constant flux of ~100 people flow through K-Town each M-week (equal to eight Martian days or "sols"; see Timekeeping section for more information).

So while K-Town is certainly the largest settlement on Mars, it is not its only spaceport, and in principle any location with a spaceport and access to sufficient raw materials could grow into a K-Town or larger, given sufficient interest and investment. So why has K-Town flourished while others remain quiet backcountry outposts? Certainly K-Town has age on its side: it is one of the oldest settlements on Mars, celebrating its 10th M-year (19 E-years) this spring. But beyond longevity, its location, proximity to resources, aesthetic beauty (for the town IS beautiful; see below), wealth, government organization, investment opportunities, and culture all contribute to its success.

2. Demographics and physical organization

2.1. Demographics

People in K-Town come from all over Earth (and now, also, Mars), and as a result enjoy a high degree of ethnic and cultural diversity. While the official languages are English and Chinese, it is common to hear Spanish, French, Luxembourgish, Arabic, Russian, Japanese and Korean spoken as well. People who have lived in K-Town a long time tend to be conversant in several languages, and children in school must study at least two besides their native tongue.

In terms of population breakdown, K-Town is currently composed of 607 permanent residents and 393 visitors, with the latter consisting of 204 professionals (business, medical, scientific, etc.), 96 tourists, 44 spacecraft crew on furlough (see spaceport section for more details), 26 guests from other Martian settlements, and 23 visiting college students. In addition to the temporary visitors who arrive during every Hohmann transfer window (also known as a synodic period, equal to about 2.14 E-years or 1.14 M-years), K-Town recently welcomed 209 immigrants, 31 of which were spacecraft crew members planning to make Mars their permanent home. On the other end, roughly 5% of K-Town's population or ~50 people per synodic period opt to return to Earth due to financial, health, marital or other reasons, bringing the net immigration rate down to 159 per synodic cycle. Among colonists, there were five healthy births in the past M-year but, sadly, also seven deaths, making the net population growth rate slightly negative, though immigration far outweighs this trend.

In terms of composition by age, 50 are under 18 E-years, 874 are adults younger than 65 E-years, and 76 are seniors. Of working-age adults, 46 are college students between 18 and 24 E-years, though 50% leave to study on Earth, and are replaced by a similar number who come to K-Town to study in its unique environment. There is a small school for children in K-Town (supported by 10 teachers and staff), but due to the small size of the college-aged population, there is not a traditional college or university available. Instead, those who opt to spend their college years here learn all about the workings of its small society and many technological innovations, in a uniquely self-directed, independent study program, supported by five professors and three staff.

For the 96 tourists currently here, half stay in the single hotel in town, *The Cangwu* (named for the nearby crater and city in China), along with up to 52 other guests, and tended by 50 hotel staff. Everyone else, including remaining tourists, stay in either apartments or, if they're very wealthy, standalone homes. Other major types of employment in K-Town include medical care (90), food processing and restaurants (80), spaceport (55, though seasonally it grows to 88), government (48, including 18 in foreign embassies and 13 in the K-Town legislature), agriculture (40), manufacturing (39), tourism (27), arts & entertainment (25), maintenance (20), banking (17), scientific research (16), propellant plant operations (12), and astronauts/explorers (8). Another 86 are involved in other business activities of various kinds. The remaining 124 include non-working parents, furloughed spacecraft crew, wealthy individuals, retirees and the unemployed.

2.2. Physical layout

K-Town is arranged as a set of semi-buried airtight structures providing radiation and micrometeorite protection for residents, while allowing ample interior space for multi-story buildings and open-air parks, gardens and fields. While built mainly of opaque materials, the curved roofs contain many large glass panels to allow for ample natural light and views of the breathtaking surrounding topography that is part of K-Town's unique appeal.

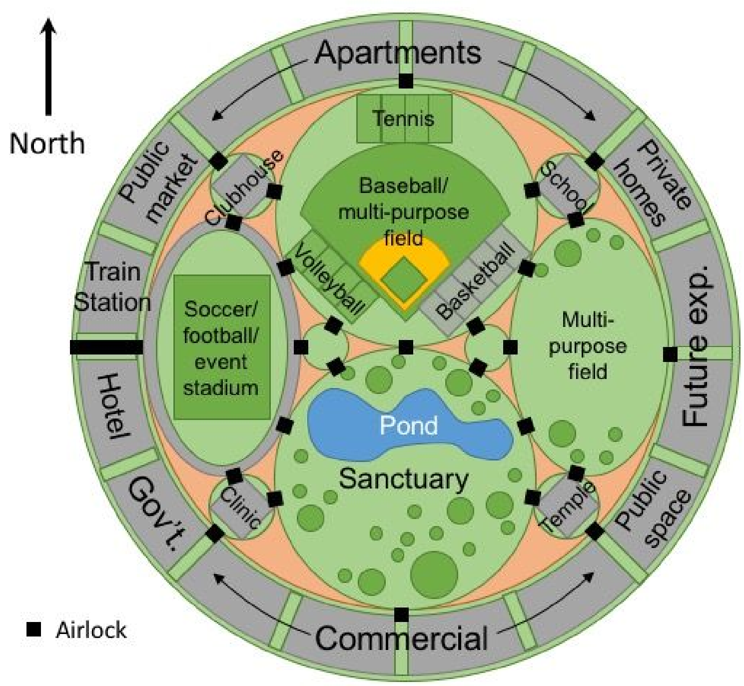

Fig. 2. Detail of K-Town central region showing parks, fields and buildings. Outer dimension is 500 m dia.

Fig. 2 shows the structures within the heart of K-Town. The centermost region contains several interconnected open spaces including a sanctuary, event stadium, multi-purpose fields, gardens, K-12 school, sports clubhouse, medical clinic, and multifaith temple. Two spaces (sanctuary and the larger multipurpose field) are enclosed by 200 m dia. domes, the largest pressurized structures currently in K-Town, representing the state-of-the-art in design. These domes are mainly composed of thick glass supported by structural steel members. Other structures are enclosed by smaller circular or oval domes, and are interconnected via airlocks that are normally open but can be closed in emergencies. Within the central region are several unenclosed natural areas (indicated by orange in the diagram) in which artists have placed a number of rock, metal or glass sculptures that can be viewed from inside the domes.

Apartments are located in the northern quadrant, with a few private homes adjacent to the east. To the west of the apartments is a public market, which sits just adjacent to the train station on the other side. Just south of the train station is the *Cangwu* hotel, flanked on the opposite side by government buildings. These public facilities are also adjacent to the sports stadium just inside the central region to allow for easy access during events. Continuing around the ring to the south are four blocks of commercial buildings, housing offices and light industrial activities such as electronics repair, 3D printing of small parts, textile manufacturing, etc. The eastern quadrant houses a multi-purpose public space and two empty blocks reserved for future expansion. A rendering of the sanctuary dome is shown in Fig. 3.

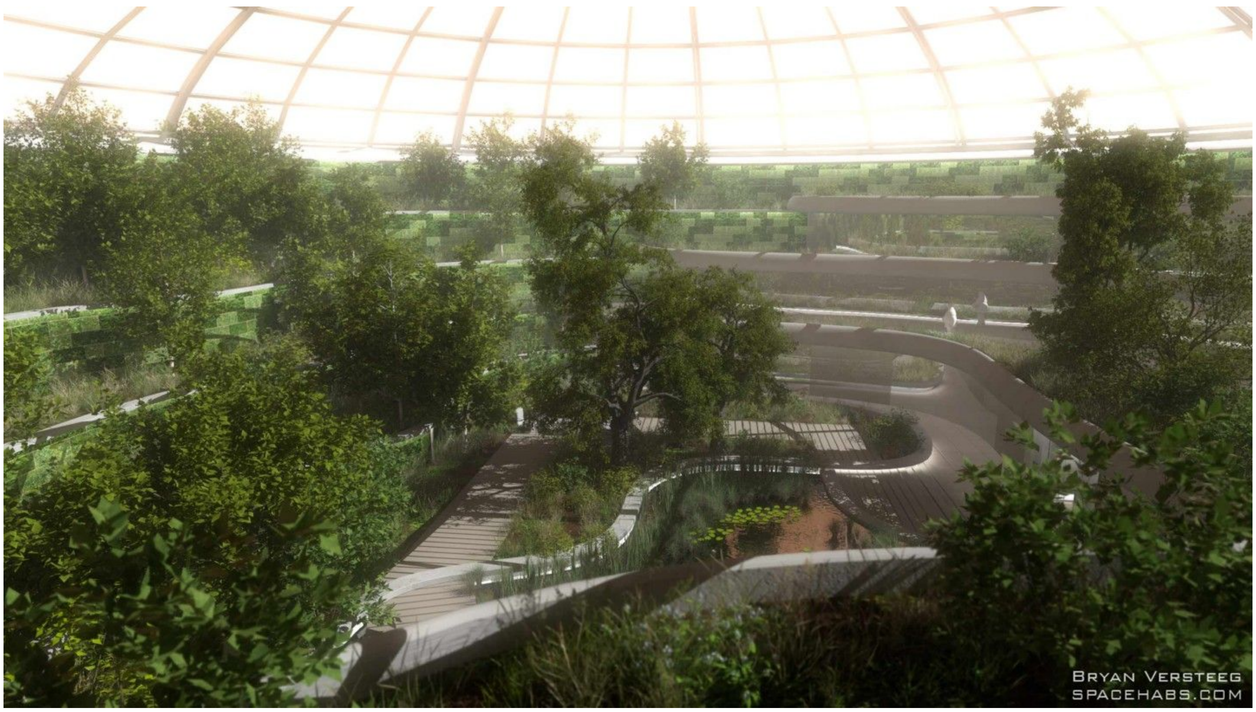

Fig. 3. Interior view of Central Park. Source: [8] (used with permission).

Fig. 4. shows the full extent of K-Town, revealing large agricultural areas surrounding the urban ring. Seven access roads radiate from the central region providing access; the eighth direction (west) is occupied by the spaceport train line. The physical structures are similar to those in the urban area, but with smaller, 25 m dia. half-cylinder rings arranged concentrically out to a diameter of 1,000 m. (Only the inner 800 m is currently in use, with the unused areas reserved for agricultural expansion.) Rings are periodically interconnected to allow free passage of people and equipment. Coverings are mainly glass in order to minimize the use of artificial lighting and efficiently utilize the available area for production; during dust storms, however, such lighting is essential to maintain crop production. Although they have less radiation protection as a result, all aspects of farming are highly automated, limiting human radiation exposure. The sole non-agricultural structure in this region is the main hospital, located just inside the town boundary at its western edge, adjacent to the spaceport train line. It is located here to provide rapid emergency access from the spaceport; see further discussion in the Medical facilities section. A dedicated airlock at the hospital also allows access from outside the town in case of emergency.

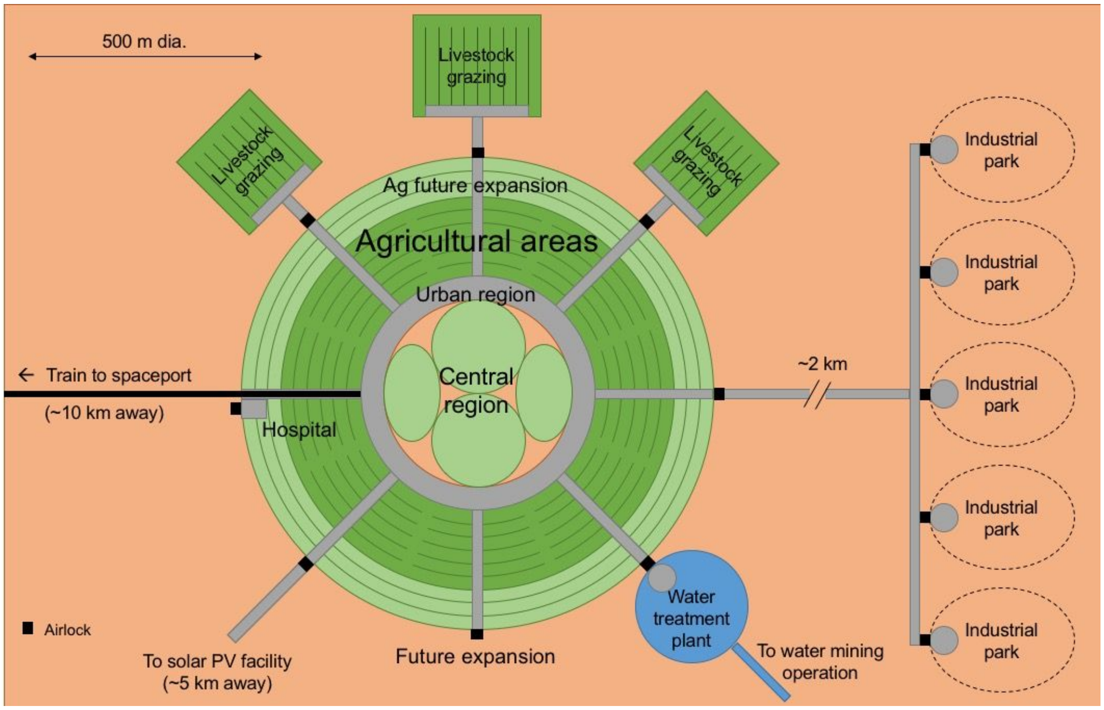

Fig. 4. Map of K-Town and vicinity

Large airlocks surround the town at the terminus of the seven access roads, separating the town from other facilities that are either too far away or present various hazards. Among those presenting hazards are livestock grazing areas, which must remain separated from the town air and water supply to prevent animal-to-human infection, as many human epidemics originate in animal populations [21]. For similar reasons, the town's water treatment plant is also isolated to prevent pathogens from entering the air supply. A different type of hazard presents itself in the form of industrial facilities, which are located ~2 km to the east through a connecting road to a series of individual airlocks at the entrance to each area. This isolation is mainly to prevent an explosion, toxic chemical release, or other mishap from affecting town infrastructure or its inhabitants. Similarly, the spaceport is located ~10 km away to the west, to provide ample area for wayward rockets to land without damaging K-Town or other critical facilities.

Finally, the central solar PV facility is accessed via a ~5 km connecting road, and is mainly isolated due to its size and anticipated future needs. A final spare airlock is present for future expansion.

2.3. Medical facilities

K-Town possesses two medical facilities: a world-class hospital staffed by 78 personnel (about double the typical number for a town of its size) located on the outer edge of K-Town nearest the spaceport train line, and a community health clinic staffed by 12 people that provides non-urgent care, mental health, acupuncture, chiropractic, optician, dentistry and veterinary services, and is located in the central region. Because the unique environment of Mars presents many first-of-its-kind research opportunities, about one-third of the hospital staff are engaged in full-time medical research, studying myriad effects ranging from the impacts of reduced gravity on bone-setting to the epigenetics of lactose intolerance among K-Town's population.

Fifteen staff, including three pilots, are on rotating shifts to operate up to three round-the-clock, rapid-response medical shuttles with the capability of reaching anywhere on the Martian surface within 100 min. via suborbital flight. Each shuttle is equipped with a surface rover to provide access in treacherous terrain, an inflatable field hospital if urgent care is required, and sufficient food, water, oxygen and medical supplies to support 10 people for up to four weeks if necessary. The shuttles operate out of the K-Town spaceport, with an emergency express train link (that overrides regular traffic) to transfer patients to the main hospital.

There is still some concern over the health of fetuses and young children in the reduced gravity environment on Mars. While research continues on rotating space stations with artificial gravity around Earth, medical authorities recommend that pregnancy, at least, take place in full Earth gravity to avoid developmental problems. Most parents thus avoid having children on Mars, but for the few pregnancies that do occur, there is a small centrifuge facility located within the main hospital that allows a woman to spend nearly her entire pregnancy at 1 g, though the experience can be isolating. As an alternative, the *Kubrick* research and tourist station currently under construction in Mars orbit will provide artificial gravity conditions ranging from micro-g to 1.5 g, and women will soon have the option of residing on this station with their partner(s) and families throughout their entire pregnancy, and for as long after birth as desired.

2.4. Plans for future expansion

K-Town's population is currently expanding by about 14% per M-year, so it needs to build 80 new dwelling units (assuming an average occupancy of two people) every synodic period, along with additional commercial, agricultural, manufacturing, power and other facilities. Within 10 M-years, K-Town expects to grow to ~4,000 people, at which point its planned urban area and overall footprint will reach capacity. Assuming growth continues at this rate, population will expand within 30 M-years to almost 50,000, and within 54 M-years (102 E-years) K-Town will be renamed M-City as it surpasses 1 million.

For these reasons, the design of K-Town is highly modular, so that multiple "copies" of the basic layout can be replicated across the K-Town Basin (an ellipse of approximately 225 km x 190 km, or 33,600 km^2, about 38% of the area of Greater Los Angeles [2]). While each K-Town "module" is designed to feature a large open space in its center, part of the M-City Master Plan is to build a huge, enclosed forested park in the center of K-Town Basin occupying ~1% of its total area or ~30,000 hectares—roughly the size of Arches National Park in Utah [3]. This park will serve as a wildlife preserve as well as "outdoor" recreation area for residents weary of living for many years in sealed and often claustrophobic spaces.

3. Major industrial activities

3.1. Overview

Physical flows of materials in K-Town are nearly closed-loop, as making things completely closed would require exorbitant amounts of time and/or energy to achieve. Designs strive for ≥95% reuse of materials, and reuse rates are expected to improve over time as technologies mature. K-Town and other space settlements will form an important proving ground for completely closed life support systems that will be required when the first interstellar starships are launched to Alpha Centauri in the next century.

While K-Town engineers understand the flows of energy and materials in their own systems very well, an overall picture requires a computer model called ASTER (Analysis of Space Technologies, Economics and Resources) [11] to provide estimates of the total flows of critical resources and energy throughout K-Town, its surrounding operations, and trading partners. In what follows here, ASTER has been used to generate these estimates, which help to set the scale of primary mining activities, water treatment, power plant, greenhouse operations, and other key activities. A summary of the major energy and material flows of interest, broken down by consumption type, is shown in Table 1.

Table 1. Major flows of energy and materials within K-Town, broken down by consumption type

			Fraction of total consumed				
Quantity	Total output	Units	Urban	Agricultural	Propellant	Other industrial	Exported
Water	88	kg/s	8.05%	35.83%	21.68%	34.37%	0.08%
Food (dry basis)	0.068	kg/s	30.57%	35.80%	0.00%	3.36%	30.27%
Fiber (dry basis)	0.0032	kg/s	49.52%	0.00%	0.00%	1.46%	49.02%
CO2	21.5	kg/s	0.00%	0.85%	97.31%	1.84%	0.00%
N2 + Ar	0.96	kg/s	4.05%	0.00%	0.00%	55.83%	40.12%
CH4	7.63	kg/s	0.00%	0.00%	85.23%	8.60%	6.17%
O2	30.5	kg/s	0.03%	0.05%	76.34%	17.73%	5.84%
Steel	0.88	kg/s	7.70%	0.77%	2.36%	78.50%	10.67%
Concrete	3.00	kg/s	22.69%	44.83%	0.08%	32.40%	0.00%
Glass	2.41	kg/s	86.72%	4.33%	0.00%	8.95%	0.00%
Regolith	283	kg/s	0.54%	0.31%	0.00%	99.15%	0.00%
Electricity	1,000	MW	0.12%	6.36%	49.03%	44.48%	0.00%

3.2. Regolith mining

Raw regolith is mined in a joint venture of K-Town Water Co., K-Town Concrete and Gravel Co., Mars Silicon Manufacturing Co. (who supplies silicon to Self-Reliant Photovoltaics, LLC), ClearView Glass, Inc., Red Planet Metals Ltd., and Interplanetary Resources, LLC, which primarily mines gold and platinum group metals (PGMs). All these companies share in the cost of mining, and then each extract their portion of beneficiated regolith to produce the materials they need. Nothing is discarded, as the tailings from the silicon, glass and metal processing operations are used as additives in concrete and gravel products. Interplanetary Resources operates a dedicated PGM mine about 50 km the southeast of K-Town where an enriched deposit was discovered two M-years ago, and now produces 15 t/M-yr (see Exports section). Elements produced as byproducts from other processes, such as chromium, vanadium, nickel, cobalt and copper, are used as additives to make high-quality metal alloys, glasses and ceramics.

Primary regolith mining is accomplished through a combination of downscaled Earth surface mining shovels [28] and trucks [29], suitably modified to operate on CH_4/O_2 fuel cells, and chemical explosives. Because of the large quantities of material involved, the extremely small (50 kg) robotic mining rovers [30] used in K-Town's early years have been replaced with heavy-duty teleoperated or directly human-driven machinery. A fleet of two shovels (15 t) and 13 trucks (5.5 t each) collectively move 290 kg/s (1,800,000 t/M-yr.) of regolith while consuming 4,400 t/M-yr. of compressed CH_4 and O_2 propellant. Raw regolith is transported to the industrial area where it is processed through a series of interdependent steps, described below.

3.3. Water, oxygen and propellant

Each human requires 12 kg of water and 0.84 kg of oxygen daily for sustenance and hygiene in K-Town. In addition, these supplies are needed for livestock and growing plants. About 40 kg/s of dirty water is treated in a sophisticated chemical-biological hybrid reactor that produces potable water with a

95% overall recovery rate. The makeup water requirements would be modest, except that an additional 18 kg/s is needed (along with 19 kg/s of CO_2 from the Martian atmosphere) to produce propellant, mainly for spacecraft. Since combustion products from spacecraft propellant cannot be recovered in space, mining must occur to continually replace them.

K-Town is located at 47 °N where frozen ground water is more abundant than in equatorial regions. The K-Town Water Co. (a collective owned by all citizens) estimate that 8% of the surface regolith by mass is water. Initially, water was extracted merely by placing airtight domes over the surface and applying heat to the subsurface regolith [10], but as this surface water was depleted and more regolith was also required for other industrial processes, the approach shifted to wholesale surface mining, whereby deposits are first fractured into manageable chunks using explosives, and the regolith is then scooped up, crushed to ~1 cm diameter particles, heated mildly to extract volatiles like water, and then passed onto other processes to extract metals and other materials.

The resulting water vapor is filtered, treated via reverse osmosis to remove salts and other impurities, and its pH and hardness are adjusted to make it acceptable for human consumption. Water used for making propellant is further treated to ultrapure standards so it can be electrolyzed without destroying the equipment. Because spacecraft propellant does not need the full stoichiometric amount of oxygen produced through water electrolysis, plenty of leftover oxygen is available, which is more than enough to supply the colony with all its needs, with much more available for export.

Altogether, ~280 kg/s of regolith is mined to produce water for the colony. The energy consumption of mining is 2.3 MW; water production, 63 MW; water treatment, 0.5 MW; and propellant production, 404 MW—bringing total water-based operations to 470 MW, nearly 50% of total colony power.

3.4. Perchlorate and other salts

Martian regolith contains ~0.5% perchlorate (ClO_4^-) by mass in the vicinity of K-Town [7]. As it can impair thyroid function, perchlorate is an acute human health hazard, but fortunately, it is very soluble in water, along with other salts (NaCl, etc.) so can be easily removed from soils and dust-exposed equipment by spraying with water. Once isolated, it is biochemically degraded into O_2 and chloride (Cl^-), which are both non-hazardous and useful. In fact, people venturing onto the surface routinely carry a portable emergency O_2 system based on bacterial enzymes to provide 60 minutes of breathable O_2, activated when ~6 kg of raw regolith are placed in a bag and water is added [7]. Of the perchlorate processed by the colony, a small amount is also converted into hypochlorite (ClO^-), a powerful oxidizing agent otherwise known as bleach, through the use of ionizing (x-ray) radiation. This is the primary disinfectant, along with ozone (O_3), used by the colony. Chloride is also used to make Cl_2 gas, hydrochloric acid, polyvinyl chloride (see plastics section) and, of course, table salt.

3.5. Food and fiber

K-Town grows all of its own food, with enough excess capacity to export ~50% of it to other locations. A wide variety of foods, including grains, fresh fruits and vegetables, herbs, legumes, nuts, animal protein (see below) as well as some specialty crops (such as coffee and tea) are grown. Plants grown for human consumption constitute 55% of total output, with animals consuming the balance; 90% of human nutrition needs are satisfied by plants. Agriculture takes up a total of 400,000 m^2, with livestock requiring 30% of this for grazing. Due to space constraints, livestock only receive 25% of their calories from grazed pasture grasses; the rest comes from intensively-cultivated plants grown along with human food in the main agricultural area. Fig. 5 shows an example of an automated greenhouse in K-Town.

While a purely vegetarian diet would reduce agricultural space, water consumption and electricity needed for artificial illumination, the modest amounts of livestock present is due both to a desire for sustainable animal products (milk, eggs and wool fiber), and a preference to eat meat among both colonists and visitors. Moreover, animal products for export are in high demand, with 50% of these and other food products exported. While the majority of animal protein comes from fish (tilapia, 55%) and insects (crickets, 23%), a small number of land animals (cows, goats, sheep, pigs and chickens) are raised to produce milk (16%), eggs (3%) and meat (3%). On a whole food basis, K-Towners enjoy 1,158 kg of animal protein per person per M-year.

Fig. 5. Interior view of agricultural area. Source: [9] (used with permission).

A small portion of agricultural land, ~30,000 m^2 or 8%, is dedicated to growing fiber plants for textiles, wood and paper. Four species are cultivated, producing 188 t/M-yr. in total: hemp (70%), flax (25%), and bamboo and hybrid poplar (2.5% each). Hemp and flax, which reach mature heights of 5 m and 1.2 m, respectively, can be grown in multiple levels. The other plant types (bamboo and poplar) reach nearly the full height of the agricultural cylinders, so are grown in a single level. These woody species are mainly used to produce ornamental and craft wood for furniture and related items, plus some paper.

3.6. Organic chemicals and plastics

Organic chemicals (containing carbon, hydrogen, oxygen and/or nitrogen) are synthesized from atmospheric CO_2 and N_2, and regolith-mined H_2O. Because there are no fossil fuels on Mars, even the simplest molecules such as methane, ethylene and benzene must be synthesized using energy-intensive processes. Once created, however, a wide variety of more complex molecules can be created. Through the use of sophisticated computer modeling and automated chemical synthesis, Terra Tempe Chemical Co. is able to create almost any desired specialty chemical from a limited number of starting materials.

Acheron Polymers, LLC produces ten basic plastics used in K-Town: polyethylene terephthalate (PET), polyethylene, polypropylene, polyvinyl chloride (PVC), polystyrene, polycarbonate, polymethyl methacrylate (acrylic), polyoxymethylene, acrylonitrile butadiene styrene (ABS) and nylon [13], which are synthesized from about three dozen reagents made from simple organic precursors. Biodegradable polylactic acid (PLA) is produced using plant-based materials, and is used extensively in 3D printing along with ABS. Together, these polymers enable a wide array of uses and significantly reduce the colony's Earth dependence. Although most polymers are not biodegradable, K-Town collects used plastics and reuses, recycles or incinerates to avoid landfill. CO_2 and water from incineration are also captured and re-used. Acheron produces 85 t/M-yr. of plastics, and exports ~50%.

3.7. Iron and steel

Due to its relatively low melting temperature, after extracting water and other volatiles from regolith, iron is extracted next via crushing and heating at 1,800 °C [23]. The resulting iron oxide (FeO) is then converted to steel using the direct reduction iron process, with small amounts of methane added to provide the carbon necessary for strength, and lime (CaO) produced as part of the cement-making process (see below), added to remove impurities. Other elements, such as chromium, nickel or vanadium, are added to produce steel alloys.

Initially, a small (6.5 t) steel plant based on the Mars Aqueous Processing System developed by Pioneer Astronautics [24] was sent as part of the initial colony equipment, capable of producing 136 t/M-yr. of steel. This steel, along with concrete from the small concrete plant, and a number of specialized materials shipped from Earth, was then used to construct a full-scale steel plant requiring 115 t of steel, 34 t of concrete and 6 t of other materials [11]. This plant was capable of producing 1,000 t/M-yr. of steel, and consumed 2.6 MW of energy. A second such steel plant was built five M-years ago, and a larger version is due to be built next year, that will once again double the total steel output capacity.

3.8. Cement, gravel and concrete

Cement is produced on Mars through the combination of lime (CaO), silica (SiO_2) and alumina (Al_2O_3), with smaller amounts of magnesia (MgO). All of these compounds are found in Martian (and lunar) regolith, but with much lower amounts of CaO and Al_2O_3 than required. By first heating the regolith to separate the lower-melting FeO, and, to a lesser extent, Al_2O_3, MgO and SiO_2, a mixture with composition of approximately 52% CaO, 31% Al_2O_3, 15% SiO_2 and 2% MgO is obtained [23]. This cement is then mixed with coarsely crushed regolith (gravel) and water to produce concrete.

Similar to the initial steel plant, a small cement plant was initially shipped to Mars, with mass 5.5 t and an output capacity of 210 t/M-yr. of cement and 1,900 t/M-yr. of concrete. This plant was used, along with steel from the initial steel plant and specialized parts shipped from Earth, to construct the full-scale cement plant in use today. This plant required 118 t of steel, 13 t of concrete and 6 t of other materials, produces 21,000 t/M-yr. of cement, and consumes 30 MW (mostly in the form of CH_4 and O_2 combustion). Like the steel plant, a second, larger version of the concrete plant is currently under construction.

3.9. Glass

Glass is produced through a combination of CaO and SiO_2, with small amounts of sodium oxide (Na_2O) other components [25]. The first glass plant was built primarily from concrete and steel supplied by the initial plants, plus 3.6 t of specialized materials imported from Earth. After this small initial glass plant was built, a total of five larger plants were constructed, each with a mass of 400 t. The total capacity now produces 143,000 t/M-yr. of glass and consumes 6.4 MW of electricity.

3.10. Aluminum, magnesium and other metals

In the process of making cement, large amounts of Al_2O_3 and MgO are produced, which are the starting points for making aluminum and magnesium, two lightweight industrial metals used in smaller quantities in K-Town for construction, electrical equipment and other applications. Aluminum is produced via the FFC Cambridge process [26], which requires significant amounts of electricity similar to the Hall-Héroult process on Earth, but without the need for cryolite (Na_3AlF_6) that is difficult to obtain on Mars due to the relative scarcity of fluorine. Instead, calcium chloride ($CaCl_2$) is used to dissolve the alumina, and due to the large quantities of chlorine available from perchlorate, this material is readily produced. Magnesium metal is made via the Pidgeon Process [31], whereby MgO is reacted with silicon metal (see

PV manufacturing below) at high temperature to produce magnesium and SiO_2. The normally unfavorable thermodynamic equilibrium is driven toward completion by distilling away magnesium vapor as it forms.

3.11. Solar photovoltaic manufacturing, power plant and heat rejection

An early goal of K-Town was to establish its own solar photovoltaic (PV) manufacturing capability, so beginning seven M-years ago, Self-Reliant Photovoltaics, LLC began making their own PV panels from Martian regolith, based on earlier lunar systems [27]. While not as efficient as those supplied from Earth, the cells are much cheaper to manufacture, and were used to greatly accelerate K-Town's energy generating capability, since the plant can produce many more panels annually than are needed to replace those powering the plant that wear out. Like the other industrial facilities described here, an initial PV manufacturing plant of mass 9 t was flown to Mars, whereupon it began producing 660 t/M-yr. (300,000 m^2/M-yr.) of solar PV cells. This was eventually replaced by the current plant, which has a total mass of 87 t, consumes 78 MW, and produces 13,000 t (6.5 million m^2) of solar PV cells per M-year.

Electricity is generated primarily through the large PV array located on the outskirts of K-Town. This plant produces 1.0 GW continuous output from a 3.9 GW peak power system, and takes up an area of 125 km^2 (including gaps between panels) located southwest of K-Town. The system stores 20% of the power it generates in a high-efficiency battery system for nighttime use, and an additional 5% in a reversible fuel cell system for long-term contingency storage during dust storms, etc. About one-quarter of the array are 40% efficient cells from Earth, and the rest are the 20% efficient, locally-made cells from Self-Reliant. All solar PV is now made locally.

A set of five 10 MW nuclear reactors left over from the earlier days of the colony are maintained as a secondary source of contingency power, along with some experimental wind turbines. It is expected that the use of the nuclear reactors will be phased out eventually, as ample supplies of H_2/O_2 fuel cells are viewed as providing all the security the colony would ever need, even if many systems fail.

Even on frigid Mars, the combination of waste heat from devices operated within K-Town, solar gain from numerous windows, and excellent insulation from the thick shielding, result in a net positive thermal balance; heat must be removed from the colony to prevent overheating. Air ducts throughout the colony pick up heat, and additional sources of high-temperature heat are injected into the air stream prior to exiting the colony. This air is then directed into a large underground heat exchanger where the energy is rejected to the –63°C Martian subsurface [12]. During this process, most of the moisture is condensed and removed, and is subsequently sent to the water processing plant for recovery and reuse.

3.12. Spaceport

The main function of the spaceport is to facilitate interplanetary transport between Earth and Mars. While the vast majority of the 2,900 spacecraft per M-year (about 4.5 per sol) that arrive or depart carry cargo, K-Town also received 423 visitors from Earth during the last synodic period and returned 264. About 75 of these arrivals were spacecraft crew, and 44 returned to Earth. The crew-to-passenger ratio for these roughly 180-day journeys is about 20%. Crew perform many essential functions including command, navigation, communications, safety, maintenance, sanitation, exercise training, medical care, conflict resolution, food preparation, entertainment, and even haircuts, are cross-trained to provide redundancy across multiple shifts and in case of incapacity.

In addition to providing access to space, the spaceport serves as a transportation hub between K-Town and the rest of Mars, via both Hyperloop train lines and suborbital rocket "hops." Four main train lines emanate from the spaceport, connecting with K-Town to the east, and various destinations to the north, west and south. The spaceport also operates the emergency medical shuttle services described under medical facilities. Altogether, surface travel makes up about 50% of spaceport passengers.

When spacecraft flights are not arriving from or departing to Earth, roughly 100 people pass through the spaceport each M-week, and during Earth-Mars launch windows, this number skyrockets to nearly the population of K-Town itself over the ~3.5 M-week period. During these peak times, spaceport staff is increased from its normal level of 55 people to 88, with most of the extra personnel provided by spacecraft crew arriving from Earth, and some seasonal K-Town labor.

3.13. Mars internet

Due to significant time delays between Earth and Mars even at closest approach, a live internet linking the two planets is not feasible. As a result, Martian citizens led by K-Town invested heavily in a large data center that runs local copies of many of Earth's websites, together with an enormous data store. Communications between the two planets employ a 25 gigabit/s (average) optical laser communications link, enabling text, e-mail, video, and even financial transactions to take place almost as quickly as the light travel time required. This system requires 10 MW to operate, plus a regular resupply of storage devices and other computer equipment from Earth, which make up ~80% of imported materials.

4. Economic considerations

4.1. Overview

K-Town's economic system was designed with five interrelated goals in mind:

1. To provide citizens with economic freedom;
2. to minimize distortions and maximize allocative and productive efficiencies;
3. to minimize rent-seeking and economically unproductive activity;
4. to encourage savings, and therefore investment, for largely self-sustaining economic growth;
5. to prevent labor shortages or surpluses.

The first goal is achieved through a universal basic income (UBI)—see details below. By ensuring citizens access to a source of funds, they are free from anxiety over their ability to live (particularly important in an environment like Mars, where even air is economically scarce) and able to pursue activities which they believe are valuable, even if they are not financially lucrative. The second goal is achieved by using depreciating licenses and a land value tax as the main sources of government revenue, rather than other distortionary taxes, such as on income or labor. Depreciating licenses contribute to the third objective, as does the cooperative ownership structure of many K-Town enterprises. The fourth is achieved by the Central Bank of K-Town as part of their mandate, and is critical to the self-sustainability of K-Town's economy. The fifth is achieved through a combination of immigration policy and the use of UBI to offset the need for living wages.

At a high level, K-Town's economy was approximated using a Solow model of economic growth. The model describes a "bootstrapped" economy: an initial infusion of resources from outside its economy is provided, after which the economy grows using almost entirely its own resources. The key idea is that a substantial amount the output produced in each time period is reinvested in additional capital stock, with which to produce more output in the future. Similar models have been used to study space colonies at Sun-Earth L5 [14] and on the Moon [15], where an initial infusion of resources from Earth is used to springboard a mostly self-sustaining space colony. While K-Town does trade with Earth, such trade is not a central driver of K-Town's economy.

K-Town's industrial base includes some heavy industries that on Earth are very greenhouse gas intensive, and now tend to be shunned due to their climate impacts. These include mining of PGMs and gold. A number of other elements including some REEs, whose carbon footprints have recently grown nearly as large, will likely become important off-Earth activities in the near future. (See the section below for details.) Products from these industries tend to be traded with Earth, though they are also extremely useful to free-space colonies, other settlements on Mars, as well as K-Town's own development.

One of the central challenges facing the initial K-Town settlers was the question of legal systems. Under the Outer Space Treaty, citizens of any given country are held to account under their country's laws. On Mars, with settlers from multiple Earth nations, such a fragmented legal system creates barriers to economic efficiency. To provide predictability and consistency, K-Town established itself as a sovereign entity with its own legal system and jurisdiction. Anyone residing within the K-Town Basin boundary must adhere to its laws, while citizenship is granted over time to immigrants and, of course, children born there.

4.2. Monetary policy

K-Town's sovereignty also allows it economic flexibility to maintain its own currency (M-dollars) and monetary policy, which is conducted by the Central Bank of K-Town (CBK), a lender of last resort that is independent of the K-Town government. The CBK allows the exchange rate between M-dollars and other currencies to float freely within a band which depends on the needs of the moment and the foreseeable next five M-years. K-Town is generally open to free flows of capital in and out of the town, subject to the CBK's guidance on how capital flow policy should be set to support the monetary policy.

Similar to the U.S. Federal Reserve (Fed) system's dual mandate, the CBK has two objectives. Like the Fed, it is required to maintain price stability, and does this by targeting a low rate of inflation (typically around 2%). Unlike the Fed, the CBK does not aim to ensure full employment, but rather aims to target the savings rate (currently around 10%). Note that the "savings" targeted by the CBK is not the same as individual consumer saving. Such savings by an individual consumer, e.g. by putting money under a mattress, reduces the level of economic activity by reducing demand for goods and services. Savings in the aggregate, such as purchases of goods produced in prior periods or purchases of interest-bearing assets such as bonds, promotes economic activity generally and investment in particular. Such investment is critical for K-Town's economy to grow.

A major issue facing central banks on Earth in the post-2008 crisis period was the "zero lower bound" on interest rates: in general, central banks were unable to move nominal interest rates below zero, limiting their ability to stimulate the economy. To avoid this situation, K-Town uses "cashless" electronic currency, allowing the CBK to charge negative interest rates when necessary.

The CBK also serves the key function of providing general, unbiased, economic analysis for the region's needs. When a new project or policy (or revisions to an existing project or policy) are being considered, the CBK provides rigorous analysis that is free of conflicts of interest. Toward that end, CBK employees are prohibited from owning shares in any specific K-Town asset. Instead, they are required to invest in a blind randomized portfolio (similar to a blind trust) of K-Town assets, where the randomization is conducted by a computer program stored in a secure facility running open-source (and therefore transparent) code. This incentivizes analysts to provide the best analysis possible, as they are equally likely to be a part of any disruptive new innovation as they are to be a part of incumbent institutions. Generically, the health of the investment portfolio is correlated with K-Town's broad economic well-being.

4.3. Immigration policy

K-Town's immigration policy is best described as "flexible, but conservative." While tourism is encouraged, the town's stance on permanent immigration depends on the CBK's assessment of the current labor market and the projected labor market situation over the next five years. Where possible, temporary needs are filled through automation or by hiring visitors who are willing to work for a reasonable wage. Where necessary, longer-term needs are met by encouraging immigration through a combination of employment guarantees and land grants.

So far, K-Town has not experienced a recession which has created a permanently-lower need for labor. However, given the political and practical difficulties of "de-immigrating" unnecessary labor, K-Town's immigration encouragement policy errs on the side of fewer rather than more immigrants. The incentives of these asymmetric adjustment costs may cause problems in the future, and will likely require further economic analysis and legislative action as K-Town grows.

4.4. Depreciating licenses

Given the importance of economic efficiency on Mars and the chance to start afresh, K-Town decided to implement a radical scheme of ownership for capital assets and real estate: depreciating licenses [22]. Depreciating licenses solve issues of inefficient investment in asset development as well as inefficient production decisions, while traditional private property as practiced in most places on Earth only address the latter issue.

The idea is a simple tweak on private property: rather than granting the “owner” of a property a license to that asset in perpetuity, they are granted a potentially-indefinite license to the asset, which depreciates over time at an annual rate, say τ, with that share passing to the government. For example, in the first M-year after an asset’s purchase, if τ=5%, the government would receive a 5% ownership share in the asset. The licenses are available for auction at the valuation set by the current license holder once every fiscal year. If any prospective owner submits a bid greater than the reserve value, the current owner is required to sell to the prospective owner for the value bidded. To avoid incentives to assign arbitrarily high valuations, the current owner is required to repurchase the depreciated τ share of ownership from the government at their assessed price. The cost of repurchase is effectively a self-assessed license fee.

K-Town does not apply depreciating license ownership to all assets. Rather, the mechanism is concentrated on goods with public-resource qualities, like land and natural resource rights. Financial investments such as bonds and annuities, consumption goods such as food, and physical assets such as buildings and vehicles operate under a traditional private property model. To ensure people security in their residences, homes are treated as a combination of consumption and investment goods. An individual’s primary place of residence is treated as an asset providing a stream of consumption services, giving them private property-like rights to reside without worrying about licenses. Any additional properties they own are treated as investment goods, and subject to the depreciating license structure. Renters in good standing are guaranteed the rights to completion of their occupancy agreement regardless of changes in building or land ownership.

4.5. Land value tax (LVT)

The highest-level principle of public finance is, “tax the least-elastic decisions first.” This minimizes deadweight loss from the tax discouraging economic activity while raising required revenues for public services. Economists on Earth have generally regarded the availability of land as inelastic with respect to taxes: no matter the tax rate on land, the available stock of land on a planet is unlikely to change, though terraforming Mars could change this dramatically. An LVT, most often associated with economist Henry George, capitalizes on this feature of land by taxing its unimproved value.

LVTs have several desirable properties. First, since the availability of land is essentially inelastic with respect to taxes, they do not discourage productive economic activity. Second, since they are levied only on the unimproved value of land, they provide land rights holders with incentives to maximize the land’s productivity. Third, since the tax burden scales with the amount of land held, they discourage the type of asset concentration which leads to individual entities acquiring market power, and encourage a more equal distribution of resources throughout society.

Depreciating licenses applied to land implements a LVT. While LVTs on Earth suffer from incentive problems in valuation – the incentives of the assessor may not be aligned with society’s interest in accurate valuations, in K-Town, the tax/auction structure of depreciating licenses encourages those with the most information about the value of unimproved land to value it as accurately as possible.

To allow people time to learn and incentives to start acquiring land, K-Town initially divided land into uniform hectare-sized plots with survey information attached, and auctioned the plots to potential colonists at low – but still revenue-raising – prices. The caveat, to ensure that potential colonists intended to use the land productively, was that the purchaser was required to claim the land in person on Mars within the arrival time from the next two launch windows. This system was phased out for existing properties, and the full depreciating license system for land phased in, at the end of 2045. New land grants to encourage immigration are given a 5 M-year grace period of depreciating license exemption.

4.6. Universal Basic Income (UBI)

All citizens of K-Town are entitled to a monthly stipend administered by the CBK. Note that tourists and other non-permanent residents (e.g., non-citizens) are specifically excluded from the UBI; if they run out of funds, they are offered to either become citizens and therefore eligible for the UBI, or are sent back to Earth. This UBI stipend is designed to provide a minimum subsistence standard of living; it is not glamorous by any means. Indexed annually to the cost of living in K-Town, it affords one a basic (one-room) residence; water, air, heat, electricity and internet; and adequate sanitation, nutrition, health insurance and pre-college education. Universal health insurance ensures that nobody is denied care for lack of funds, and college education is subsidized to ensure that everyone who works can afford it. The full value of the stipend is awarded to every citizen over 9.5 M-years (about 18 E-years) of age; parents of minors are provided with a per-child supplement that is always less than the full adult amount.

4.7. Exports and competition with other space resources

Earth has superior manufacturing and supply chain capabilities, but its deep gravity well makes it more expensive to ship anything into space if it can be made elsewhere. The lower gravity of the Moon and asteroids, however, present in some cases challenging economics for Mars to compete against. The main advantages Mars has over other space resources are twofold: 1). superior manufacturing capabilities in some areas, due to a larger human presence and more developed infrastructure, and 2). abundant carbon and nitrogen, two elements that are very limited on the Moon and many asteroids.

In the first category, materials such as metal alloys, glasses and ceramics, as well as complex equipment such as rocket engines are either not possible to make, or can be made in only limited quantities, in locations other than Earth and Mars. K-Town has over the last 5 M-years begun to make such high-quality materials, and its export business to both Mars and Earth orbits is growing.

In the second category are many carbon- and/or nitrogen-containing materials including food, fiber, plastics, organic chemicals, fuels, fertilizers, and N_2 used in breathing air and inert blanket gas. (Argon, which is present in Mars' atmosphere at about half the concentration as N_2, is also used for this purpose.) K-Town's greenhouses grow twice the food and fiber required for its citizens, with the balance being exported to remote locations on Mars and in space. Non-biological materials containing carbon and/or nitrogen are also produced in excess of K-Town's need, with the balance exported. Moreover, water and oxygen, while not competitive with the Moon on cost, is exported to Mars orbital locations as well as some nearby asteroids.

There are also some materials that are now cheaper to make in space than on the Earth, such as PGMs and gold, that require enormous amounts of energy to purify and take a high toll on Earth's environment. Production of these materials on Earth is now strongly discouraged in favor of importing these materials from space. While many of these materials are also available from asteroid and lunar resources, K-Town's superior material independence has driven down operational costs, whereas the Moon and asteroids still tend to be heavily dependent on Earth for basic supplies such as food, labor and even building materials, which are very expensive to ship there. Energy is also now cheaper in K-Town that just about anywhere other than Earth, thanks to the completion of its 1 GW power plant built from indigenous solar PV. About 1% of global PGM demand and 0.1% of gold demand are now supplied by K-Town mines. Jeff Bezos' vision of moving heavy industry into space [5] is starting to become reality.

Other elements, such as xenon, tantalum, indium and gallium are still a few years away from profitability, as are the REEs (particularly neodymium and praseodymium, used in wind turbine generators and maglev trains) [4]. While not yet economical, K-Town (and Mars in general) is beginning to invest in mining operations of these elements, as well as atmospheric separation to produce liquefied xenon gas. About the only energy-intensive activity that K-Town has not yet begun investing in is the fabrication of integrated circuits, where the Moon has had a considerable head start.

Finally, some materials made in K-Town are valuable simply because they're Martian. Examples include wine from Terra Tempe vineyards, wool sweaters from K-Town's sheep herd, and wooden objects produced from K-Town's small tree plantation, as well as ordinary Mars rocks that collectors on Earth can't seem to stop buying. A handful of investors on Earth are also somewhat crazy about Mars gold, and are willing to pay a premium for it over Earth-mined gold. While exports of "Made on Mars" goods aren't as large as other types, it represents an important additional income source to the colony.

The vast majority of exports is in fact propellant: specifically, liquid methane and oxygen, which make up ~75% of exports by mass. Table 2 lists all of the currently exported commodities from K-Town.

Table 2. List of commodities exported to Earth and orbital destinations

Item	Destination(s)	Mass flow (t/M-yr.)	Gross revenue ($M/M-yr.)	Costs ($M/M-yr.)***	Profit ($M/M-yr.)
Metals and metal parts	Orbital**	5,586	729.0	656.1	72.9
Water	Orbital**	4,118	537.5	483.7	53.7
Oxygen	Orbital**	5,713	684.6	616.1	68.5
Nitrogen/Argon	Orbital*	22,851	3,488.3	3,139.5	348.8
Food (dry)	Orbital*	1,224	203.5	183.2	20.4
Propellant - LCH4	Orbital*	27,931	4,896	4,407	490
Propellant - LO2	Orbital**	100,086	12,824	11,542	1,282
Plastics	Orbital*	40.0	6.6	6.0	0.7
Organic chemicals	Orbital*	79.9	13.3	12.0	1.3
Fiber	Orbital*	93.1	15.5	13.9	1.5
PGM	Orbital*	9.13	373.0	335.7	37.3
"Mars" gold	Orbital*	5.93	382.3	191.6	190.7
"Made on Mars" products	Orbital*	18.8	17.3	4.5	12.8
Total		167,757	24,171	21,591	2,581
*45% Earth orbits, 35% Mars orbits + Lagrange points, 10% nearby asteroids, 10% Mars surface					
**Only non-Earth orbits: 70% Mars orbits + Lagrange points, 20% nearby asteroids, 10% Mars surface					
***Includes 90% of launch costs + production costs					

4.8. Economic growth overview

Export revenues make up ~10% of K-Town's economy, which is expected to be nearly $250 billion/M-year by the end of 2049 (note all costs are expressed in 2019 U.S. dollars). This value is close to what K-Town economists estimated back in 2030 when the colony was established, with an initial seed investment of $250 million. They used a Solow model with labor-augmenting technology to project

K-Town's long-run growth and the initial investment required in 2030 to get to the 2049 level. The model consists of three main mathematical features:

1. A production function which related capital and labor stocks to value of output
2. A law of motion for the capital stock
3. An exogenous savings rate (set by the CBK) and exogenously-assumed labor and labor productivity growth rates

The production function is of the Cobb-Douglas type with labor-augmenting technologies and constant total returns to scale in capital and labor. This implies that capital and labor are complements in producing valuable output, and that there are decreasing returns to scale in either input individually. That is, doubling only the amount of capital available while holding labor constant will result in less than double the output produced, and similarly for labor, while doubling both capital and labor will double the total amount of output produced. The long-run growth of this economy will be driven by growth in the productivity of labor-augmenting technologies.

The economists took a three step approach to calculating the initial investment level required to achieve the target size of K-Town's economy in 2049. First, they calibrated the parameters using calculations from ASTER (see section 3 above), stated assumptions about K-Town's population, and historical analogy to similar economies (primarily Japan and post-war "Asian Tiger" economies). Second, they used these calibrated values with the export numbers from ASTER to estimate K-Town's Gross Domestic Product (GDP) and the growth rate of GDP in 2049. Third, they used the estimated K-Town GDP and its growth rate to project backwards to 2030 to back out the initial investment of productive assets. This approach yielded an initial investment of $250 million in 2030, which was sufficient to cover initial seed equipment of habitat modules and conversion of Martian resources into construction materials.

It is important to note that the 2030 estimate from this process was only for productive assets set up on Mars. It did not include the cost of transporting those resources to Mars, nor one-time fixed costs such as acquiring intellectual property licenses, non-recurring engineering expenses, or imports of supplies before the colony became productive. These additional costs were estimated to be $2 billion in 2030, making the total initial investment $2.25 billion.

With an economy now >100x this size per M-year, this was a debt that has easily been paid and now returns substantial dividends to early investors. K-Town currently receives capital inflows valued at approximately $30 billion/M-year, and is one of the most attractive off-world investments.

5. Political, organizational and social aspects

5.1. Governmental organization

As mentioned earlier, K-Town is a sovereign governmental entity separate from any Earth entity. Its jurisdiction applies to any person or equipment residing within the borders of K-Town Basin as depicted in Fig. 1. Its authority derives from its constitution, which is now recognized by every nation on Earth, and is organized as a representative democracy with a unicameral legislature, similar to many smaller nations on Earth. These representatives are elected every M-year through district voting. All citizens who have reached 9.5 M-years of age (roughly 18 E-years), including those living abroad, have the right to vote. The legislature currently consists of 13 representative, or one per ~50 citizens, of which there are 656 in total. As K-Town grows, its constitution will eventually cap the number of representatives at 100.

A mayor is separately elected through direct vote of all citizens every two M-years. The mayor's office, plus associated governmental offices, employ a total of 12 people. The police department consists of three people (sheriff and two deputies) while the fire department employs two people, relying heavily on volunteers in case of emergency. Foreign embassies of eight Earth governments plus the United Nations constitute an additional 18 people.

5.2. Democracy 2.0: Quadratic voting system

The founders of K-Town wanted to ensure that all citizens had equal representation, but recognized that individuals would have different strengths of feeling on different issues and would want to be able to express those feelings. To achieve this, the founders enshrined Quadratic Voting (QV) into K-Town's constitution.

Rather than a "one-person-one-vote" assignment, QV gives each voter a stock of non-transferrable, non-storable "vote credits" for each voting occasion. The voter is then free to allocate credits in favor of or against any issue on a ballot, with the cost of vote credits being quadratic in the number of votes allocated to a particular issue. For example, expressing one vote ("for" or "against") on a generic ballot issue would cost one vote credit, while two votes would cost four vote credits, three votes would cost nine vote credits, and so on. This system allows voters to express not only a "for" or "against" preference on issues, but also the strength of their preference. Given a fixed stock of vote credits, it forces voters to prioritize the issues that are most important to them. In general, this ensures that voters with the strongest opinions on any given issue can be heard even if they find themselves in the minority. Giving each voter the same initial allocation of vote credits ensures that all voters have an equal say in the process *ex ante*.

QV fixes a number of limitations with voting systems still in use on Earth, many of which fall under the heading of "problems of intense preferences" [16]. For example, one-person-one-vote systems tend toward tyrannies of the majority, with large numbers of voters with weak preferences able to drown out the voices of minorities with strong preferences. In situations where relevant domain knowledge is likely to be concentrated among a minority of experts, this can lead to significant welfare losses when uninformed majorities choose scientifically-poor options. Similar problems emerge in cases of minority rights, when the majority is either unaware of or indifferent to problems faced by a minority of the public. One way to think of the difference between QV and one-person-one-vote methods is that the latter approaches all *ration* votes, while QV *prices* them. At a high level, the efficiency gains from QV can be viewed as gains from removing an artificial supply constraint and moving to marginal cost pricing. Although QV is considered a radical concept on Earth [17], economic research in the 2010s established QV as an approximately optimal system of voting under general assumptions [18].

5.3. Timekeeping

Mars' day ("sol") is only slightly longer than Earth's. While several proposed systems were discussed and debated prior to the first human arrivals, early settlers quickly converged on a 24-hour clock identical to Earth's except for a "timeslip" of 39.587 min. once per sol [20] that K-Town, by dint of its seniority to other settlements, has chosen by overwhelming vote to take place at midnight. Settlements located in different time zones around Mars observe the timeslip at a different local hour to maintain synchronized hours across the planet, with a few exceptions. Generally, people use the timeslip to socialize, perform rituals or sleep; work during this period is considered taboo.

One M-year consists of 668.6 sols. Settlers wanted to preserve the familiar 12-period calendar from Earth, so they created M-months consisting of either 55 or 56 sols, and known by the same names as months on Earth. Eight M-months have 56 sols and three (May, August and November) have 55 sols. February has 55 sols for two M-years out of five, and 56 sols for the other three, in a pattern reminiscent of Earth's leap day. January 1 is designated as Mars' winter solstice ($L_s = 270°$).

After a period of experimentation, the citizens of K-Town and most other settlements on Mars enthusiastically chose an eight-sol M-week as being more conducive to recreation and recharge, offering an entire extra sol each M-week to do with as they please. As a result, M-months consist of (nearly) seven M-weeks each. Most businesses adhere to a five-sol work week as on Earth, with a three-sol weekend, but many self-employed people choose to work four sols followed by four sols of recreation (or work every other sol), claiming it results in better overall productivity. Many dedicate the “extra” sol to community service, and important civic functions such as elections always take place on that day.

5.4. Culture

Being dedicated to building a positive future on Mars, the culture of K-Town is one of intense discussion and debate about the best ways to accomplish things technically, economically and socially. Recognizing the many past and present failings of human society on Earth, K-Town citizens are committed to making things better by trial-and-error, self-criticism, and failing fast. People have learned to critique the method or outcome and not the people, though exceptions still occur. Storytelling in particular is used as a means of developing intuitive models for visualizing the future, and its practice is widespread throughout all aspects of society. Science fiction as well as historic accounts of Earth-bound explorations are routinely drawn upon, and sophisticated mathematical models are frequently used for forecasting.

K-Town is an exciting place to live, and looks forward to growing in size and stature. Join us!

6. Acknowledgments

The authors would like to thank Jason Aspiotis, Andrew Granatstein, George Lordos, Raluca Ostasz, Kai Staats, Brian Unger, Bryan Versteeg and Eric Ward for their contributions to the report.

7. References

1. *Wikipedia*, 2018. Arcadia quadrangle. Last edited 13 Nov. https://en.wikipedia.org/wiki/Arcadia_quadrangle. Accessed 2 Feb. 2019.
2. *Wikipedia*, 2019. Greater Los Angeles. Last edited 19 Jan. https://en.wikipedia.org/wiki/Greater_Los_Angeles. Accessed 2 Feb. 2019.
3. *Wikipedia*, 2019. Arches National Park. Last edited 16 Jan. https://en.wikipedia.org/wiki/Arches_National_Park. Accessed 2 Feb. 2019.
4. *Critical Materials Institute*. 10 Things You Didn't Know About Critical Materials. Ames Laboratory, U.S. Department of Energy. https://cmi.ameslab.gov/materials/ten-things. Accessed 2 Feb. 2019.
5. Stella, R., 2016. To save Earth, Jeff Bezos wants to move heavy industry to outer space, *Digital Trends*, 1 June. https://www.digitaltrends.com/cool-tech/jeff-bezos-says-big-industry-factories-should-be-built-in-space/. Accessed 7 Feb. 2019.
6. Parker, J., 2018. Colonization of Lower Gravity Worlds: Concerns and Solutions to Human Gestation and Development, *The Mars Society*, 21st Annual Convention, 23 Nov. https://www.youtube.com/watch?v=HPck20Jpyio. Accessed 7 Feb. 2019.
7. Davila, A. F., D. Willson, J. D. Coates, C. P. McKay, 2013. Perchlorate on Mars: a chemical hazardand a resource for humans. *International Journal of Astrobiology* 12(4), DOI: 10.1017/S1473550413000189. https://www.researchgate.net/publication/242525435_Perchlorate_on_Mars_A_chemical_hazard_and_a_resource_for_humans. Accessed 8 Feb. 2019.
8. Versteeg, B., Crater dome cam 2, Space Habs. http://spacehabs.com/mars-gallery/#gallery-43873/19. Accessed 9 Feb. 2019.
9. Versteeg, B., Mars-farm-cam-22-Aa, Space Habs. http://spacehabs.com/mars-gallery/#gallery-43873/18. Accessed 9 Feb. 2019.
10. Kornuta, D., et al., 2018. *Commercial Lunar Propellant Architecture: A Collaborative Study of Lunar Propellant Production*. https://www.philipmetzger.com/wp-content/uploads/2018/11/Commercial-Lunar-Propellant-Architecture.pdf. Accessed 9 Feb. 2019.
11. Greenblatt, J. B., 2018. ASTER tool presentation to NASA, Emerging Futures, LLC. http://www.emerging-futures.com/single-post/2018/10/07/ASTER-tool-presentation-to-NASA. Accessed 9 Feb. 2019.

12. Williams, D. R., 2018. Mars Fact Sheet, NASA Goddard Space Flight Center. Last edited 27 Sept. 2018. https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html. Accessed 9 Feb. 2019.
13. Creative Mechanisms, 2016. The Eleven Most Important Types of Plastic, blog, July 21. https://www.creativemechanisms.com/blog/eleven-most-important-plastics. Accessed 5 Sept. 2018.
14. O'Neill, G.K., 1979. *The High Frontier: Human Colonies in Space*. Morrow.
15. Sandler, T. and Schulze, W., 1981. The economics of outer space. *Natural Resources Journal*, *21*(2), pp.371-393.
16. Posner, E.A. and Weyl, E.G., 2015. Voting squared: Quadratic voting in democratic politics. *Vand. L. Rev.*, *68*, p.441.
17. Lalley, Steven P., and E. Glen Weyl. 2018. "Quadratic Voting: How Mechanism Design Can Radicalize Democracy." AEA Papers and Proceedings, 108 : 33-37.
18. Weyl, E.G., 2017. The robustness of quadratic voting. Public choice, 172(1-2), pp.75-107.
19. Maynard, M., 2019. Veggies May Be Healthier, but in 2018, Americans Will Eat a Record Amount of Meat, *Forbes*, 2 January. https://www.forbes.com/sites/michelinemaynard/2018/01/02/veggies-may-be-healthier-but-in-2018-americans-will-eat-a-record-amount-of-meat/#70cfb7d19b92. Accessed 23 Feb. 2019.
20. Robinson, K. S., 1992. Red Mars. Random House. ISBN 0-553-09204-9.
21. Zoonotic Diseases, Centers for Disease Control and Prevention, U.S. Department of Health & Human Services. Last reviewed July 14, 2017. https://www.cdc.gov/onehealth/basics/zoonotic-diseases.html. Accessed 20 Mar. 2019.
22. Weyl, E.G. and A. Zhang, 2018. “Depreciating Licenses”. *SSRN* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2744810. Accessed 30 Mar. 2019.
23. Hashimoto, A., 1983. “Evaporation metamorphism in the early solar nebula-evaporation experiments on the melt FeO-MgO-SiO_2-CaO-Al_2O_3 and chemical fractionations of primitive materials,” Geochemical Journal 17:111-145. https://www.terrapub.co.jp/journals/GJ/pdf/1703/17030111.PDF. Accessed 29 Mar. 2019.
24. Berggren, M. R. Zubrin, C. Wilson, H. Rose, and S. Carrera, “Chapter 21: Mars Aqueous Processing System,” In: Mars: Prospective Energy and Material Resources, V. Badescu, ed., Bucharest, Romania, ISBN 978-3-642-03628-6.
25. Johnson, R. D. and C. Holbrow, 1975. Space Settlements: A Design Study, Appendix J. National Aeronautics and Space Administration Summer Study, Ames Research Center, NASA SP-413. https://settlement.arc.nasa.gov/75SummerStudy/4appendJ.html. Accessed 29 Mar. 2019.
26. Tripuraneni Kilby, K. C., L. Centeno, G. Doughty, S. Mucklejohn, and D. J. Fray, 2006, “The Electrochemical Production of Oxygen and Metal via the FFC-Cambridge Process,” Space Resources Roundtable VIII, Lunar and Planetary Institute, 31 October–2 November. https://www.lpi.usra.edu/meetings/roundtable2006/pdf/tripuraneni.pdf. Accessed 29 Mar. 2019.
27. Ignatiev, A. and E. Caroll, 2018. “Lunar Vacuum Deposition Paver,” Survive and Operate through the Lunar Night Workshop, Lunar and Planetary Institute, Columbia, MD, 13 November. https://www.hou.usra.edu/meetings/survivethenight2018/eposter/7013.pdf. Accessed 30 Mar. 2019.
28. Caterpillar, 2019. “6015B,” Specifications. https://www.cat.com/en_US/products/new/equipment/hydraulic-mining-shovels/hydraulic-mining-shovels/1000012100.html. Accessed 30 Mar. 2019.
29. Caterpillar, 2019. “785D Mining Truck,” Specifications. https://www.cat.com/en_US/products/new/equipment/off-highway-trucks/mining-trucks/18089285.html. Accessed 30 Mar. 2019.
30. Mueller, R. P., R. E. Cox, T. Ebert, J. D. Smith, J. M. Schuler, A. J. Nick, 2013. “Regolith Advanced Surface Systems Operations Robot (RASSOR),” NASA Technical Reports Server, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130008972.pdf. Accessed 30 Mar. 2019.
31. Wikipedia, 2018. Pidgeon Process. Last modified 28 Sept. https://en.wikipedia.org/wiki/Pidgeon_process. Accessed 30 Mar. 2019.

