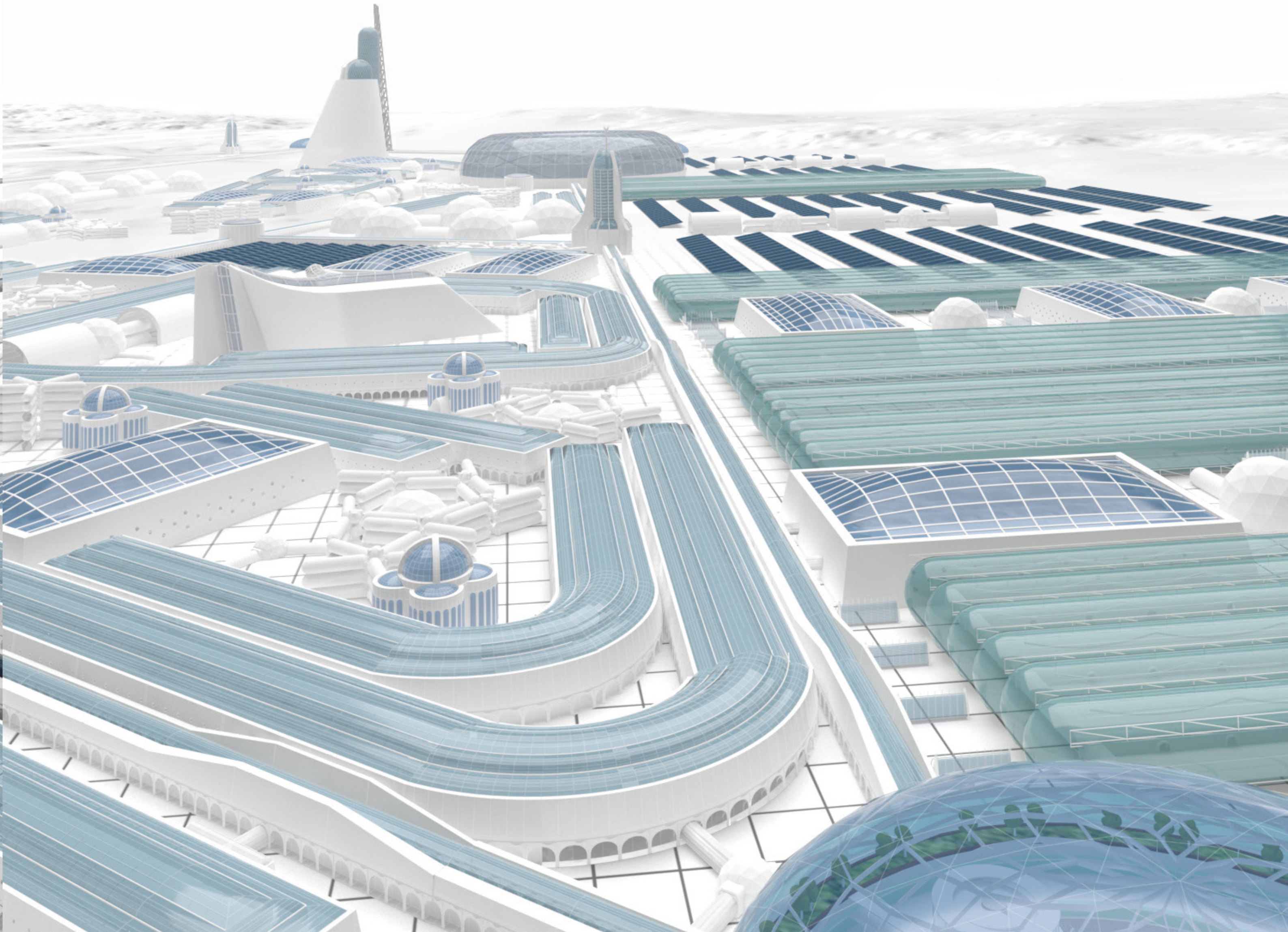
NEXUS AURORA
Open Source Space Colonisation

Mars City State Design

June 2020



PROLOGUE

Mars' thin atmosphere makes dawn fast. As the sunlight sweeps across the eastern slopes of Hellas Planitia, the glimmer of Orbital-1 visible overhead, banks of lights across the city fade up in a warm glow. The weather outside is cold and crisp with a medium wind, and the climate control creates a corresponding chilly breeze down the streets.

As clocks hit 7:30 Standard, alarms begin to buzz across the habitat. The household murmurs into life. Zach Ellis is first up, his commute demanding an early start. His wife, Vala Zubrinova, works inside Willow Node itself, so is afforded the luxury of a morning shower. The two children, Jasmine and Alexei, lope down to the kitchen.

Breakfast is different for all family members - Zach prefers seeded rye toast, the children have cereal with soya milk and Vala treats herself to a smoked salmon sandwich. Alexei finishes the milk with his cereal, and shouts to the voice assistant to add some to a shopping list.

Zach leaves the house first, donning his work uniform and heading out onto the habitat central street. The buildings are fairly old, so lack the decorative flourish seen on newer buildings around the city, but the facades are painted in a charming range of pastel colours. Despite the amber glow of the lights, the street is lit with flickering patterns from the metres of shielding water overhead.

Vala hops onto a packed metro car (standing room only at rush hour, this line serves over 10 thousand people in Willow Node) and is whisked away towards the central hub. She makes a quick change at the ring interchange to the Northern Branch, onto a train full of workers also heading to the Mars United Biopharma plant.

Zach also changes at the ring interchange, but he swaps to Eastern Branch and a train headed for the Node main rail station. Once there, he takes a familiar route to the northward departures and through a series of airlocks into a low, rounded passenger pod. Bang on time, the entry hatch closes and a robotic crane lifts the pod onto the bed of a waiting train. With only the faint vibration of an electric motor and the rumble of hardened steel tracks, the train pulls away from Willow Node.

Jasmine and Alexei cycle past the ring interchange and through pedestrian tunnels, which lead them to the Node's central dome. In keeping with the Node's name, the designers have chosen to fill the open spaces between the buildings in the dome with willow tree-surrounded ponds. The two children scurry off the trains and join the throng of students heading into the school complex.

Vala works at Mars United Biopharma as a production line supervisor and quality control checker. Vala's work is easy, monitoring purity of the product at various stages of production with frequent sampling, and trimming inefficiencies out of the robot schedule. The primary output of the MUB plant here is salicylic acid, which gives Willow Node its name.

Zach works outside his home Node as an automation engineer at the vast steel rolling facility in Geim Crater - the city's industrial center. He disembarks the train near Geim Crater and joins the crowds of engineers and operators heading through pedestrian tunnels into the crater complex. Zach splits his day between supervising the semi-autonomous robots on the mill floor, and working in the control room on advanced automation software for the same robots - part of the never-ending project to reduce the load on human operators.

Back in Willow Node, Alexei and Jasmine are in classes. Alexei is 9 years old, so he is still learning from the standard curriculum. Morning is classroom teaching, and after lunch he takes part in a depressurisation drill. After school finishes, he joins his friends at the rock climbing club, walking to a climbing gym a few minutes from the school. Jasmine is 22, and hopes to progress to Further Learning next year after her capstone project concludes. Morning classes are a mix of compulsory and optional side modules. But Jasmine's real passion is geology, so she spends the afternoon working on detailed plans for her geological research trip this summer. Like all native Martians, she ever seeks to push the boundaries of human exploration. Her research trip will be a bold undertaking, but one that she is ready for.

After the working day concludes, all the members of the family return to their apartment in the habitat on the outskirts of Willow Node. Jasmine and Alexei help Vala in the kitchen, preparing a meal of tuna steak and boiled potatoes, while Zach tidies the living room. The meal lacks expensive imported spices, but Vala is practiced at working with the herbs available from the grow boxes on the windowsill. After dinner, Alexei runs from the table early, eager to call with friends across the city. Jasmine heads off to her room to work on a lab report, as Zach and Vala settle down on the sofa to watch some imported Earth sitcoms.

This isn't a typical family on Mars - just an example of a single family living in, more or less, happiness and tranquility. Just one of a quarter-million families living in their quarter-million homes, who can call a red planet **home**.

CONCEPT

To cut free the shackles of our limited capacity for thought and drive humanity towards a shining future, where unhindered technological progress is coupled with considerate, human-centric design: this is our optimistic vision of societal progress - this is the grand goal of Nexus Aurora. The plans for a Martian colonisation program with a flourishing colony of one million people by the year 2100 encapsulates this vision. It is our garden city full of open vaulted spaces, natural light and community.

In order to build a city of one million, we must do more than live off the land. We must use Martian resources to build an industrial base to rival terrestrial nations. Quarries, algae photoreactors, farms and atmospheric compressors providing feedstock to vast rolling mills, additive manufacturing systems and chemical reactors: we account for all these systems and more, powered by Martian-made nuclear reactors.

Building designs must adapt to withstand the pressure, radiation and temperature extremes of the Martian surface, while simultaneously enabling happiness and fulfillment for the inhabitants by providing airy, light-filled community spaces. We reject the concept of cities built of tunnels and underground habitations. Nexus Aurora has wide boulevards and urban parks made possible with pressure vessels of basalt-fibre reinforced plastics (BFRP), utilizing the powerful radiation-shielding effect of water to protect our residents.

Such a city would be expensive to build, as a huge amount of industrial equipment (and a huge number of people) would need to be transported from Earth. As with any financially significant endeavor, Nexus Aurora will not be profitable in its early decades. A thoroughly planned economy balances income from tourism, exports of construction materials and services to other Mars colonies with the continual high cost of imports. A democratic government will ensure stability and freedom for the population.

This 20-page report represents less than 1% of the technical documents that comprise the comprehensive plan of Nexus Aurora. Our plan is a phased approach that grows the Martian colony from a tiny outpost of 20 Earth-dependent colonists into a self-sufficient settlement, expands into a formidable industrial base, and finally to become a thriving and autonomous nation.

Nexus Aurora is not tied to any one nation or organisation. It draws on the spaceflight legacy of NASA and ESA, the technical experience of SpaceX and Mitsubishi, and the industrial base of Germany and Japan. Only by opening up both space itself and the design of our future in it can we embolden humanity to move beyond our current limits. Thus, we present:

Nexus Aurora, Open Source Space Colonisation

CONTENTS

1 BUILDING NEXUS AURORA

1.1 Preparation

The requirements of building a large permanent settlement on Mars are very different to those of short-term missions. Our number one priority for site selection was availability of water in the form of glaciers. Water forms the backbone of industry on Mars, so the typical landing sites in the low northern latitudes are simply inadequate for our purposes. Instead, we are forced to consider relatively high latitudes.

The second priority is easy access to a range of minerals. Without accessible and rich deposits of metals, we will have considerable difficulty building a city. Remote sensing from satellites, particularly the MRO, is invaluable for broad-stroke analysis but cannot detect the kinds of small deposits that can be targeted by mining operations. For that, we must turn to geology and areology, and it tells us that the best indicator of varied, rich deposits is a history of fluvial and volcanic activity.

Based on these primary criteria, and a whole raft of others too extensive to discuss here, we eventually selected a landing site on the edge of Dao Vallis, situated on the eastern rim of Hellas Planitia.

The advantages of such a site are considerable, beyond the geology. The landing zone is 4.5 km below Mars datum, which offers higher atmospheric pressure, more height through which to aerobrake, and better protection against radiation. Our landing site is also only 600 km from Talas Crater: one of the lowest elevation areas on Mars and a prime candidate in the search for life.

However, this site is not without its difficulties. The southern latitude, combined with Mars' orbital eccentricity, makes the winters of Hellas cold and dark.

The thicker atmosphere also means harsher dust storms. Despite these barriers, Dao Vallis is the chosen site of Nexus Aurora, and we have plans to overcome these challenges.

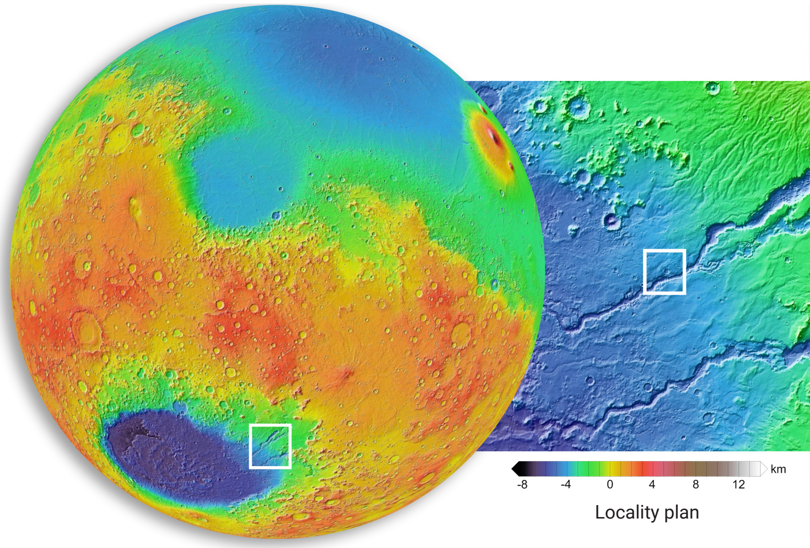
The selection of a landing site is but the first step - we must know every centimetre of the landing zone and the surrounding regions before we set foot on the surface. An extensive satellite network, both to provide the first connectivity for the colony, and to extensively survey the landing site, is required. A ring of satellites in areostationary orbit, communicating with Earth in the EHF band, will provide a stable communication line for robotic operation. Deployed simultaneously to these is a fleet of low polar orbit observation satellites, gathering high-resolution imagery of the landing zone (in both visible and various EM bands, for better remote mineralogical analysis). The deployment of this constellation is anticipated for the 2024 transfer window.

However, satellites can only take us so far. To precisely locate and analyse mineral veins on the surface, survey robots are required. These robots will accompany the first landed cargo ships at the landing zone and represent a radical departure from the NASA doctrine of valuable, high-redundancy rovers. Instead, a Starship will deploy dozens or even hundreds of small, lightweight surveyors onto the landscape. These will spread out in a swarm, providing a wealth of data about the underlying geology and geography of the landing zone in the form of elevation maps and core samples. This will be invaluable for the laying out of habitats, mines, scientific outposts, and transport lines as the city swells beyond the confines of the initial landing zone.

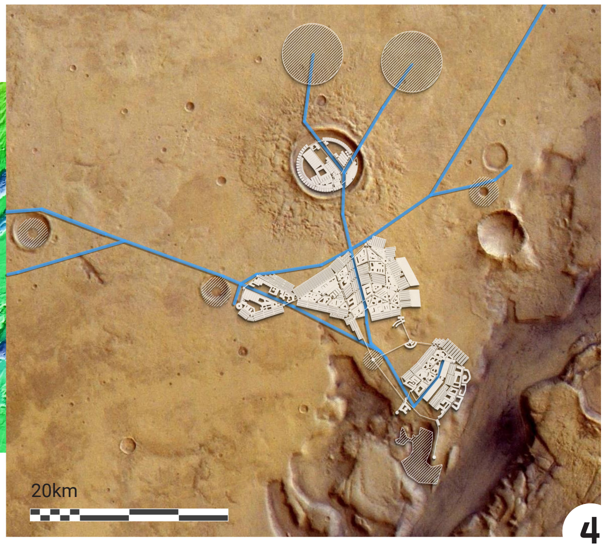
1.2 Buildings

Building on Mars requires a radical rethinking of terrestrial ideas for what a building should look like, how it should function, and how it should be built. We have identified four key ways in which building on Mars is significantly different to Earth, with solutions visible in the concepts of every building.

1. **Material availability** - reducing manufacturing energy in the later stages is vital for reducing power consumption, and restrictions on material manufacturing on Mars severely limit potential building materials and techniques.
2. **Pressure** - to maintain Earth-like pressures inside buildings of any practical size, the walls must withstand enormous tensile hoop stress. This poses the biggest practical limitation on building size and form.
3. **Radiation** - despite popular misconceptions, Mars is not rendered utterly inhospitable by cosmic radiation[1]. However, to avoid long-term health concerns, appropriate shielding must be provided



Locality plan



to reduce exposure by 80% in order to fall within terrestrial safety limits.

4. **Temperature** - the southerly latitude of Nexus Aurora means we can expect rapid radiative heat loss[2]. This challenge is reversed in later years of the project when effectively rejecting heat from industry becomes a major challenge.

In the first years of Nexus Aurora, all building materials must be shipped from Earth, and ease of construction and assembly is critical. To this end, we have developed a standardised modular structure, based around a 6 m diameter cylindrical pressure vessel with steel end-domes and reinforcing rings. This modularity is useful - modules can be split into two levels for work and habitation, or kept in a single high-ceilinged space for workshops and machinery. The interchangeability of the end-domes allows modules to be rearranged on the surface, creating vastly complex spaces from a few simple building blocks. These modules are so versatile that we expect them to continue to be reused even as the city grows thousandfold, such as in remote outposts and small industrial sites.

We have determined that burying these modules, or building underground in general, is significantly worse than structures on the surface (protected from radiation by a rammed-soil brick arch, sufficient to bring exposure below the 50 mSv annual limit for radiation workers in the US[3]). Underground structures require tunneling equipment to be operated with associated costs in mass, time, and energy, and the subsurface of Mars has sufficient unknowns to make such an endeavour very risky. In comparison, brick vaults can be built autonomously, provide superior thermal insulation, allow easy maintenance and repair, and create a shielded space for both outdoor work and running utilities.

The interior of the modules will be simplistic, drawing on the wealth of existing development work[4] for the design of short-term Mars bases. Emphasis will be placed on creating both personal spaces for citizens, and small-group community space to facilitate group cohesion.

Constructing buildings in-situ makes use of an abundant material at our landing site - basalt in the form of drawn fibre, a material with incredible tensile strength, which can be made into an airtight composite with a thin layer of imported plastic. Basalt fibre reinforced plastic composite[5] (BFRP) is an incredibly well-suited material for our purposes - strong enough to make pressure vessels tens or even hundreds of metres in diameter, very low import weight, and production energy a fraction that of traditional materials like sintered bricks and steel. Weaving basalt fibres into a net-like structure to reinforce clear polymers (at a fraction of the cost of glassmaking) allows for vast greenhouses.

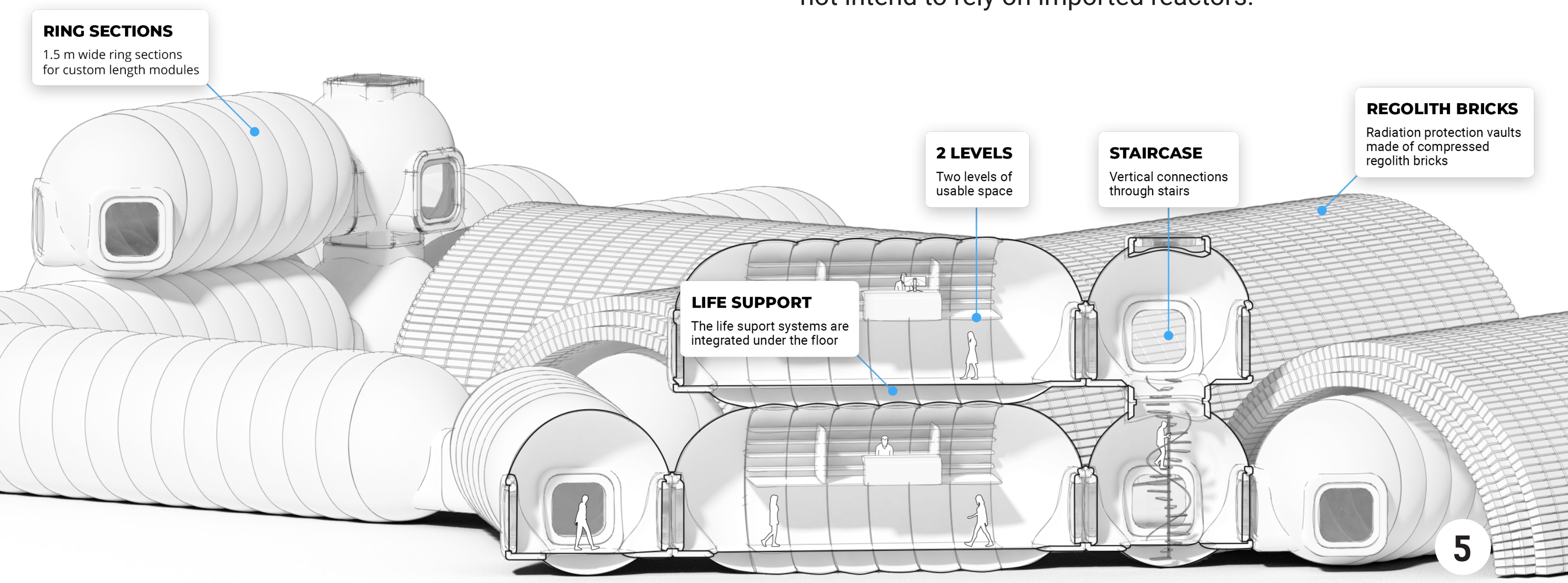
Detailed landing site analysis will provide information for selecting the best place to locate the initial settlement - the landing area contains a sizable collapsed lava tube[6], which (structural integrity allowing) would provide an excellent large volume to hold dozens of habitation and industrial modules with protection from weather and radiation.

1.3 Necesities of Life

Power production in the first stages of colonisation is provided almost entirely by solar energy, backed up with lithium-ion batteries. This is possible due to the power system's ease of deployment, excellent power density, and decentralised nature, which provides built-in redundancy against failure. We have determined that ideal power cells are thin-film CIGS cells[7]. These can be deployed as roll-out blankets by robotic systems to provide power to the pre-colonisation equipment or fixed-tilt arrays on carbon-fibre frames with a combined density of 100 g/m^2. The complete design weighs just 120 tonnes, which includes a 6 MW-average output grid including solar arrays, batteries, transmission equipment, and emergency backup methalox generators. This provides the basis for the life support of the first few hundred colonists, along with power for early farming and industry.

Power demands will increase soon after initial colonisation. Expanding the power system is simple; more arrays and batteries can simply be added at will. Battery capacity is designed to ensure continuity of power to vital systems and will not be used to sustain industrial operations, so large capacity is not required.

We have also explored the use of Small Modular Reactors, particularly the Westinghouse eVinci[8] and other candidates for the Megapower programme. These reactors would be connected to aero-derivative turbines[9] for an expected output of 5 MWe and 3 MWth at 90 t shipping weight. However, such a design is dependent on these reactor programmes coming to fruition and favourable geopolitics for launching tonnes of nuclear fuel, so we do not intend to rely on imported reactors.



Mars Base made of 6m Modules

The atmosphere for the colony is provided from two sources; the first is compressed and separated Martian atmosphere, and the second is hydrolysed water. The CO_2 from the atmosphere can be repurposed for the farming industry. Oxygen regeneration will be provided primarily by plants, with LiOH and KOH scrubbers[10] providing backup regeneration. A comfortable atmosphere will be maintained at 80 kPa for superior redundancy across the city. This will be achieved with a decentralised system of heaters, both electrical and district heating with industrial heat. Humidifiers and dehumidifiers will also be utilised to maintain atmosphere.

The location of our landing site is only a few kilometres from a known glacier with over a cubic kilometre of ice, which exceeds requirements for water extraction. The most effective extraction technique identified is the Rodriguez well[11], which is already used for water extraction from glaciers on Earth and can produce 37 L/day/kW.

To prevent the need for excessive purification, we plan to have separate processing for greywater, which is reused in toilet flushing, farming, etc., and blackwater, which is treated as potentially hazardous and will be processed with Earth-similar standards. At larger scales, processed waste will be used as industrial feedstock. Methane from anaerobic decomposition and nitrogen-rich compounds are both valuable products, rather than waste.

Unlike the hyper-optimised spacesuits designed by NASA, suits for long-term use in Nexus Aurora should focus on ease of manufacture and repair along with simplicity of use with minimal training and practice. The EVA suit created by the design group must function for 8 hours on the surface, with all the comforts and safety systems expected from a spacesuit. Easy use of a range of tools is also required.


EVA Suit

In order to meet these criteria, a partial pressure suit[12] is optimal, and it will be similar to those worn by fighter jet pilots, providing pressure to the skin through corset-style threading. Thermal regulation and protective outer layers are worn over this pressure-providing suit.

When working indoors in structures with lower safety factors, the extra layer of safety provided by a rapidly-deployable egress suit is required. A breathable atmosphere is provided by a zip-up hood that can be worn comfortably behind the head when not in use, and can provide 5 minutes of breathable air to facilitate evacuation.

These two pieces of uniform, EVA suit for surface operations and IVA suit for frequent indoor use, provide the colonists with function, comfort, and safety outside housing habitats.

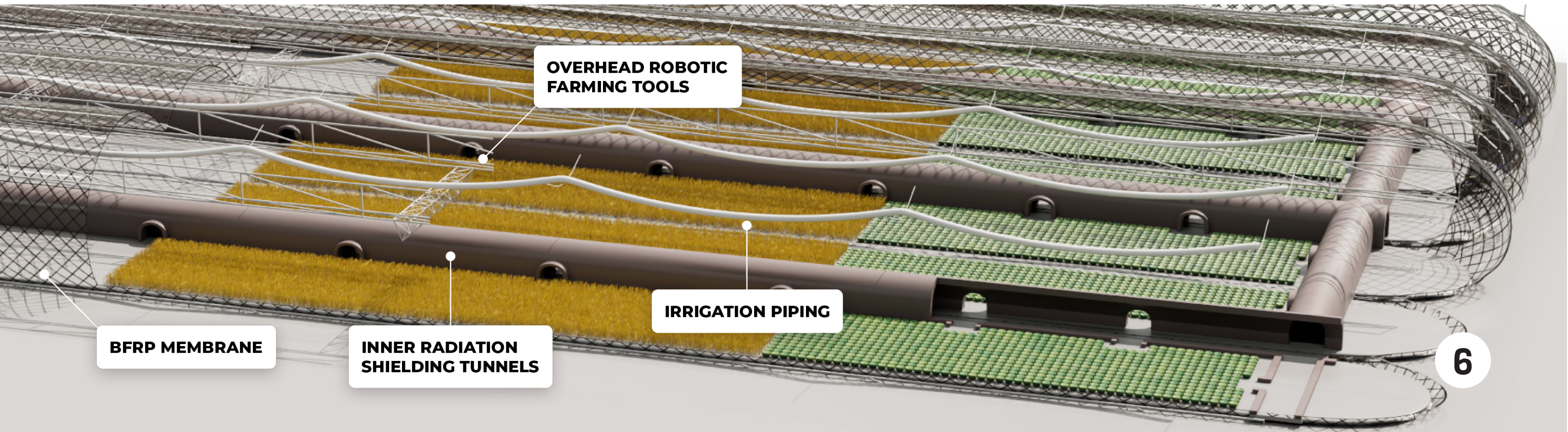
An essential part of the construction and growth of Nexus Aurora is the near-omnipresence of autonomous and semi-autonomous robotic systems. Robotic systems allow the automation of menial, arduous, or dangerous jobs. In order to improve interoperability and reduce the number of discrete systems that need to be transported to Mars, a modular robotic platform will be developed. This allows a common drivetrain and control system to be attached to a wide range of tools and equipment systems, with quick interchangeability provided by surface workers or even other robotic systems. Some of the requirements that have been explored, with the inputs of design teams across the Nexus Aurora project, include mobile cranes, brickmaking and bricklaying robots, logistics robots for the transport of cargo both indoors and outdoors, and humanoid avatar robots to allow for remote maintenance and construction.

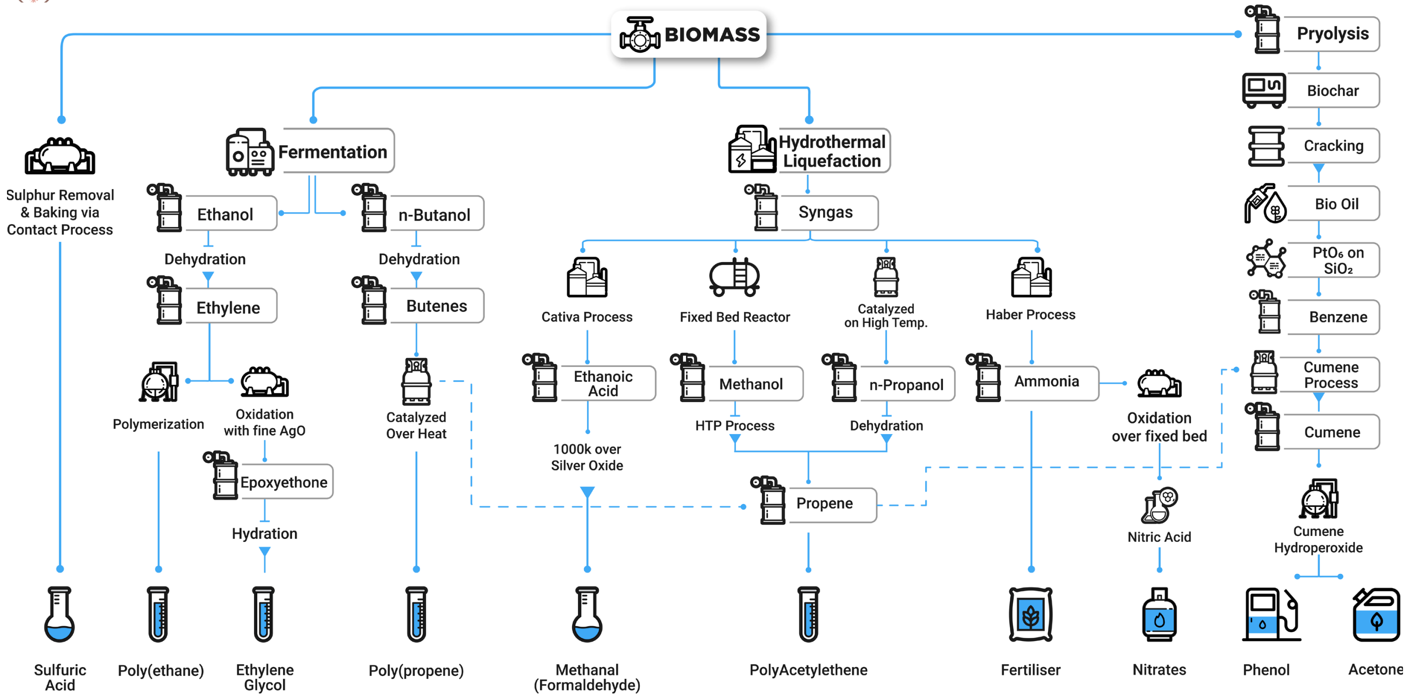
1.4 Production and Industry

Nexus Aurora cannot rely on Earth imports to build the vast majority of Martian structures due to the steep shipping costs. Therefore, an industrial base for producing construction materials is essential.

Mining in the early days of the colony is an entirely mechanical process, with backhoe and bulldozer excavators moving regolith from targeted areas to industrial sites. As demands for minerals increase and diversify, more traditional methods are required: open-pit quarrying and in-situ leaching. The former will provide the tens of thousands of tonnes of basalt[13], iron ore and soil needed per year, and will require blasting using perchlorate-based explosives[14] manufactured on Mars. The latter is more appropriate for small high-concentration deposits of specialist minerals such as copper, sulfur, and

Basalt Fiber Reinforced Plastic Farming Modules





uranium. The study of sediments along Dao Vallis will provide a low-cost solution to finding mineral deposits if they exist anywhere along the ancient riverbed.

Farming serves two roles in Nexus Aurora: not only does it feed the colony, but it also provides an essential industrial feedstock. Plants can fix carbon dioxide into complex molecules with efficiency far above any artificial process - we intend to make full use of this.

The basic structure of our large farms is simple. It has joined rows of 5-20 m diameter BFRP tubes up to 1000 m long, with the lower segment filled with either processed soil (to remove perchlorates) or water. These tubes are wide enough for large-scale machinery to operate inside.

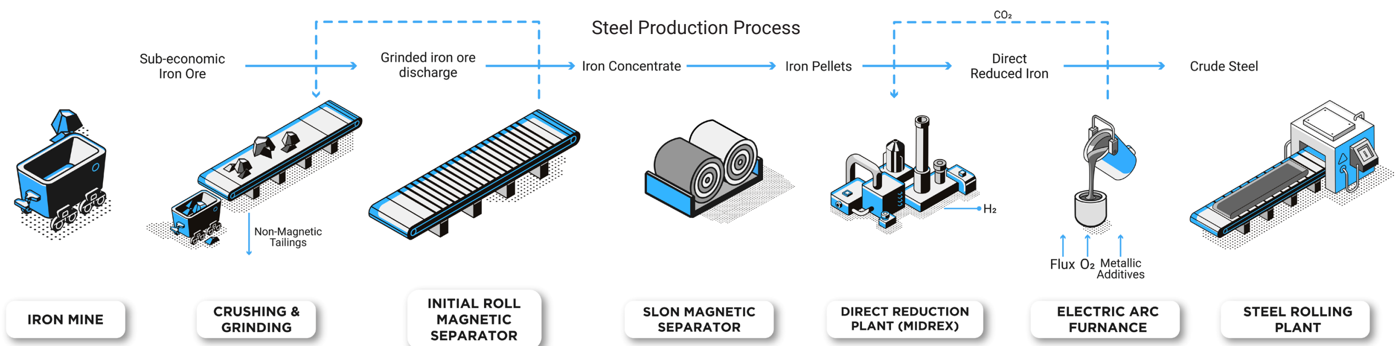
The nature of producing greenhouses on this scale leads to an interesting and rarely-considered conclusion. Building greenhouses requires between 200 and 600 kWh per square metre. Artificially lighting and heating the same area to maximise yields requires 800 kWh per year[15]. Therefore, provided industry can keep up, it is energetically cheaper in the long run to simply build more greenhouse area than resort to high-density, high-energy farming techniques like stacked hydroponic basins or artificial lighting.

The downside of this strategy is that a huge farm area is needed, even with the use of a CO_2-rich atmosphere and fertilisers. Because of the psychological and ecological need to grow a wide range of crops, we estimate that 150-170 square kilometres of farmland will be needed to comfortably feed a city of 1 million people[16].

The range of uses of farmland across the city are:

- Carbohydrates like potatoes, wheat, and corn
- Protein-rich plants such as legumes and soybeans
- A range of mixed nutrition fruits and vegetables
- Oil-producing plants (e.g. rapeseed, sunflowers)
- Providing open space for both views and exercise for colonists, as well as auxiliary atmosphere regeneration
- Water-filled or partially flooded farm structures for fish farming. Fish form a key part of the food system; they digest plant waste and are an excellent low-energy protein source.

Steel has been used for a case study in metal processing, as it is both a critical material for building purposes and for industry. Ore from mines and quarries is mechanically crushed, separated magnetically to increase purity, and then reduced to iron in a direct-reduction plant. This DRI plant would initially use hydrogen, as this is the most energy-economical of the various reducing gases proposed in the literature[17], but may switch to methane if it is more available from biochemical sources. The iron from this plant will be alloyed to various steels as required in electric arc furnaces[18], and then shaped in a rolling mill. Cold-rolled steel is preferable to machined or hot-rolled steel in almost all cases, due to superior strength, manufacturing speed, and wastage.



One of the staples of construction materials is basalt fibre, which is used extensively in BFRP due to its high specific strength of 1790 kNm/kg and exceptionally low manufacturing energy of just 1.1 kWh/kg[19]. It is produced through simple melting and extrusion of mined basalt, using rejected process heat to reduce power consumption. Another material used widely across the colony is sulfur concrete, which can be cured on the surface without climate control - a significant benefit for exterior structures.

One of the biggest industrial challenges on Mars is the total lack of petroleum. It may be possible to build a city using no or only imported hydrocarbons, but it is far more promising to consider how such chemicals can be produced.

The usual method of producing base hydrocarbons is chemical synthesis from atmospheric CO_2, most commonly the Sabatier process, producing methane. This will be used for the production of many simple olefins and carbonyls, but larger hydrocarbons are generally more complex. A promising route is biochemistry; in particular, the processing of biomass to produce various targeted compounds. The biomass input is provided by waste plant matter and algae. Algae can be grown in photobioreactors with extremely high growth rates (0.38 kg/m^3/day), making it ideal for this purpose. This biomass is liquefied under high pressure to produce oil that can be processed very similarly to petroleum. The benefit of biopetrochemistry is the ability to use modified terrestrial methods for processing, rather than developing entire new synthesis routes. With this feedstock, a chemical industry capable of producing many invaluable consumables, such as rocket propellant, fertiliser, explosives and surgical anesthetics.

The most important product of this bio- and electro-petrochemical industry is the output of large volumes of energetically cheap plastics. This is the key to producing large structures in BFRP with low energy demands and no imports from Earth, and thus grow Nexus Aurora at the rate needed to reach a population of 1 million.

1.5 Logistics

While the vast majority of transport in Nexus Aurora occurs indoors, large surface rovers are needed to move cargo, equipment, and occasionally people to installation sites on the surface. As with robotics, these rovers will be outfitted with a wide range of modular tools for specialist construction (crane, bulldozer), extraction (drill, backhoe), and transport roles[20] (flatbed cargo, pressurised transport for crew). A rough analysis estimates that we will need approximately 90 rovers within the first 10 years of the colony, with corresponding equipment. The rover platform is sized for transporting very large loads, including whole habitation modules or tens of tonnes of raw regolith for industry. To prevent excessive wear (a problem that has plagued Mars rovers for decades), a shape-memory Fe-Mn-Si[21] alloy will be used for the wheels of rovers, as well as the wheels and exposed moving parts of other heavy-capacity outdoor equipment.

Transport of equipment inside and outside the base will be handled almost entirely by robots working either autonomously or remotely controlled. During the first decade of colonisation, we expect to unload over 8,000 tonnes of material from Starships, which will require a dedicated cargo handling infrastructure. Autonomous rovers in flatbed configuration will be used to carry equipment between storage yards and installation sites. Dedicated cargo airlocks will allow multiple tonnes of material to be moved in and out of the base, with air jets removing contaminating dust. Inside the colony, small autonomous carts[22] will transport equipment from storage and production to consumers.

2. ENGINEERING NEXUS AURORA

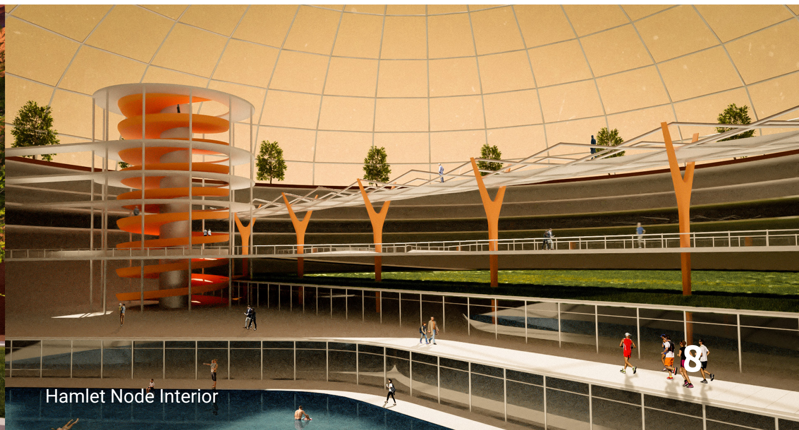
2.1 Structures

Nexus Aurora will far outgrow the 6 m modular housing that is designed for the early years, but the design principles will be maintained in the cavernous habitation spaces. BFRP will remain a heavily-utilised material, used for pressure vessels across the city. However, the single short tubes will be superseded by clustered cylinders hundreds of metres long, building up vast interior spaces (in which houses, shops, and recreation spaces are situated) to create soaring expanses and bustling city blocks that transport the citizens far from the reality of a totally enclosed existence.

The smallest commonly-used structure of this “clustered cylinder” architecture is the 570Hab, a structure composed of four 18 m diameter, 150 m long BFRP cylinders, providing a total usable land area of 8000 m^2 at a minimum height of 8 m - sufficient for three-storey buildings. The hab can house 570 people at a high population density[23] (living in compact apartments with narrow streets), but we have specified a maximum of 400 to allow for spacious streets and sufficient natural light.

Radiation shielding is incorporated into structural elements of the 570Hab, and it is taken to extremes. All four sides of the hab are enclosed with a 5 m thick wall of rammed soil blocks (ingress and egress provided by steel tunnels of various sizes). The roof is covered with a 3 m layer of water (kept liquid by a low-pressure layer above) that provides necessary radiation shielding[24] while allowing natural light inside.


City Block Interior


Hamlet Node Interior

The interior of the 570Hab will take a number of forms, the most common being a city block. However, uses such as multi-storey manufacturing facilities and recreational open space have also been identified. The exact nature of the cityscape that can be built within the confines of such a structure is detailed later in this document.

Despite their size, 570Habs only form the smallest and least dense sections of mass housing in Nexus Aurora - analogous to the suburbs of a terrestrial city. For the buildings that make up the urban core, the principle of clustered cylinders is taken a step further with the Air Mattress concept. This still uses joined BFRP cylinders with overhead water for shielding, but on a significantly larger scale and in a less standardised fashion. Each Air Mattress would be individually designed with consideration of both the available land area and local ground features, to avoid having urban cores be too homogenous.

Due to the specialised design nature, it isn't possible to give detailed information about specific instances of the Air Mattress. Plans are dependent on survey maps in greater detail than is available from orbit. However, various concepts for district centres involve Air Mattresses with a land area of over 150,000 m^2, equal to many city blocks. Such a large internal volume will contain not just homes for thousands of people but wide tree-lined boulevards, urban parks, and shopping districts. Air Mattress structures provide the space to create the environment most like a terrestrial city on Mars, and we intend to make full use of this.

And yet, even Air Mattresses do not provide enough space for some activities. They will have an exceptionally large footprint but the limits of the BFRP cylinder model constrain maximum height, and will require steel tensile rods to fill the space. The final piece of commonplace architecture is the centrepiece of neighbourhoods across Nexus Aurora, providing soaring volumes and open public spaces.

A 200 m diameter dome, formed of a flattened sphere of transparent BFRP half-buried inside an appropriately sized crater. Radiation shielding is minimal, but the risk is deemed acceptable given the psychological and sociological advantages of having large open community spaces and the short times that people will spend in the domes. 200 m is close to the practical limit of the possibilities of transparent BFRP domes - larger structures may be possible with stronger plastics (such as Dyneema[25]) but these have not been extensively considered on grounds of energy to construct and manufacturing complexity.

The interior space will be entirely given to community use - considered uses include playing fields, forested parks, plazas for social gatherings, and amphitheatres. These domes also act as central transport hubs, where pedestrian arteries for the city connect.

Beyond the relatively regular, repeated buildings that provide housing (as well as the simpler structures for farms and industry, discussed in other sections of this report) we have identified the need for a number of landmarks to be built around Nexus Aurora. These serve a number of purposes - a few are functional but the majority serve as cultural and social nexuses for the population of Nexus Aurora. We have considered dozens of ideas (from radio telescopes to skyscrapers to mausoleums) but a few have been developed in more detail, and one has proven such a compelling concept amongst the community that detailed 3D models have been produced. A few of these landmarks are:

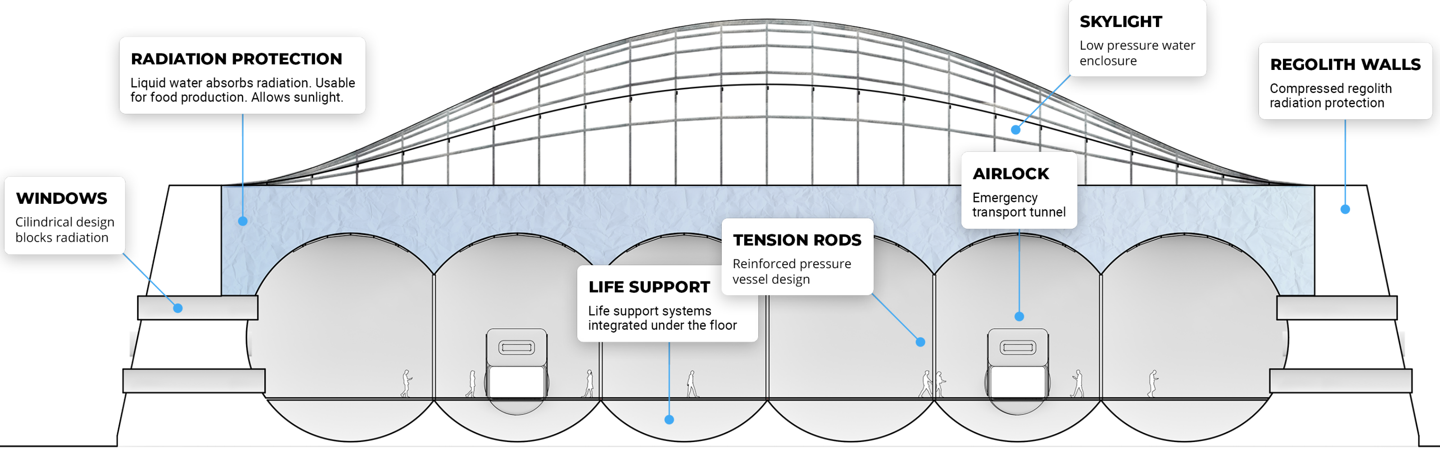
Monument to the Fallen Wanderers, a structure that serves as both a resting place for the remains of those who die in the early stages of the colony, and a memorial to all those who made incredible sacrifices to make colonisation of Mars possible.

Another proposal is large infrared telescopes[26] for astronomical research. The Martian atmosphere absorbs virtually no infrared, especially in MIR and FIR bands, and 50 m collectors would be able to carry out observations of protoplanetary discs and galaxies in the early universe, impossible to do through Earth's wet atmosphere.

The most developed landmark is called the Tree of Life. The giant redwood tree, planted on the first day of the founding of the colony, will require a structure that can be expanded around it for support and protection from the environment. The interior will contain a spiralling walkway stretching from the ground to the canopy of the tree, along which people can walk or sit.

The Tree of Life is intended to embody the growth of the colony, from humble sapling to an ecosystem towering over the landscape in a structure built entirely from Martian materials. It will outlive the entire founding era of the colony and may even live to the day when Mars is terraformed to the degree where a pressure vessel is not needed.

570Hab section



All of the structures in Nexus Aurora, be they vast Air Mattress habitats or tiny modules holding industrial equipment, will be placed with careful regard to both human experience and the demands of the surface. Urbanism on Earth in the past century has seen cities spread across the landscape without regard for the nature that existed before, and grow in directions led by commercialism and short-sighted thinking that have rendered the lives of many city-dwellers a miserable concrete monotony. We cannot afford to repeat either of these mistakes on Mars.

Human experience is the driving force behind our architectural decisions. We have chosen to design walkable streets and wide-open spaces to prevent a glum tunnel city. Light and fresh air are precious and the colony will flounder without them, even though they are difficult to design and build. Every habitat is designed with a view, either over communal spaces or the Martian landscape, to ensure that people do not feel boxed in by the city.

Simultaneously, we are placing our buildings carefully with due regard for the natural landscape of Mars. Habitats will lie along contours and follow riverbeds, and we will not flatten the landscape with bulldozers. Through this philosophy, we can build a city better suited for habitation than perhaps even Earth cities.

2.2 Infrastructure and Transport

To feed, build, and supply a colony of a million people, infrastructure projects on a colossal scale are required. In particular, to transport the tens of millions of tonnes of material per year (mostly raw ore, but also food, water and manufactured material) around the city, vehicles running on roadways are far from adequate. The energy requirements of operating such a system are enormous, as are the material demands of hundreds of kilometres of concrete roadway. Instead, rail is the far superior option.

A Martian 3 m rail gauge has been developed with the capacity to carry hundreds of tonnes per electric locomotive at 250 km/hr across the surface. This capacity is dictated by the millions of tonnes of ore that need to be transported from quarries to furnaces. Cargo cars are set up to use standard containers, and they are interchangeable with passenger modules.

The material cost of producing railways is significant (160 kg of steel and 625 kg of sulfur concrete per metre), but analysis shows that if a given rail route has a lifetime throughput of over 2 million tonnes, energy will be saved compared to vehicles running on compacted regolith. The minimum projected system size is 300 km of rail, which is easily achievable with steelmaking and mining capacity in the latter stages of the project. Rail lines will form the transport backbones of Nexus Aurora, with dense urban areas situated nearby to rail lines.

While Nexus Aurora will become significantly less dependent on imported equipment as the city population approaches 1 million, the cadence of ship landings will increase as the population swells. In order to meet this goal, over 5000 Starships (or equivalent) will be landing per transfer window by the year 2100. This requires significant ground-based infrastructure to receive, process, and re-launch so many vehicles. For this purpose, we have picked 4 crater-based launch complex sites in the vicinity of the city, sufficient to process all landings in just 100 sols.

The design of these complexes is modelled on Baikonur Cosmodrome, with trenches to funnel heat and debris away from vehicles[27]. All launch complexes are connected to the colony by rail and have extensive storage depots to process the cargo and arrivals. To mitigate risk for the colony in the event of launch or landing failure, all complexes are located in relatively high-walled craters and exclusion zones have been drawn around them to prevent damage to buildings in the event of an accident.

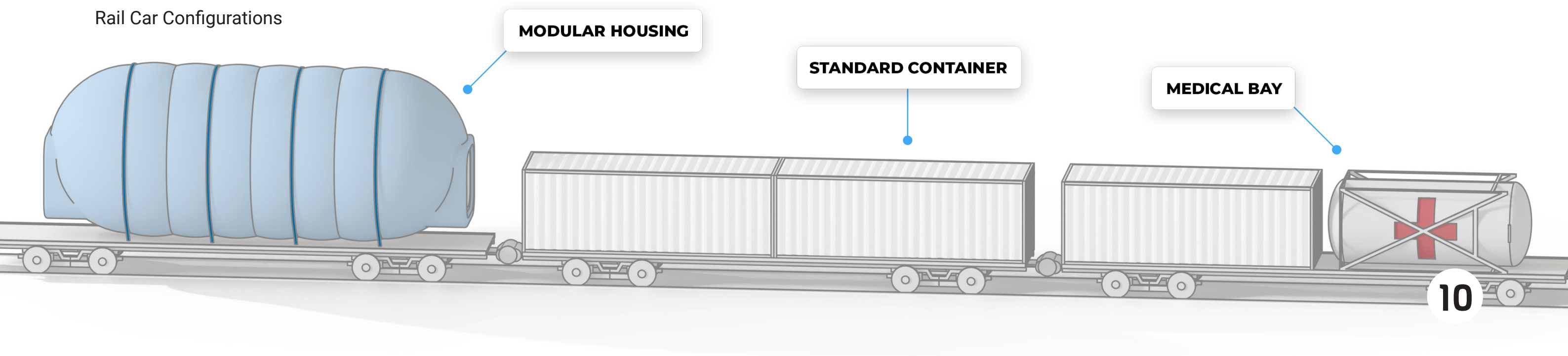
As Nexus Aurora grows, the complexity and scale of the supply chains required grow proportionally. The beauty of building a city from the ground up is that this system can be unified and controlled centrally. This allows both comprehensive control of strategic stockpiles[28], optimisation of automated delivery of goods, and prevention of waste.

Transportation routes across the colony have been designed with spaces for automated robotic systems to carry cargo. A standardised container design has been developed to allow maximum interoperability of cargo handling systems. This standard has been implemented for a variety of equipment outside containers to allow for modular production lines with automated operation.

The ultimate goal of indoor logistics is for all transport of goods or equipment further than around 25 m to be carried out by autonomous robots. This represents a significant investment for Nexus Aurora, as many of the complex robot systems will need to be imported from Earth. However, it also allows for significant improvements in efficiency, "24.6/7" operation, and removes a significant burden of menial labour (either in manual moving of such cargo, or remote control of such robots) from the inhabitants of the city. Massively automated systems such as this have been proven to be incredibly effective on Earth[29] and Nexus Aurora intends to expand this framework beyond the warehouse[30] to cover the entire city footprint.

These transport robots will be the most visible part of the city's robotic infrastructure, but they will be only a small part of it. The demands of the Martian economy and practicalities of operation on the surface necessitate the removal of human operators wherever possible; they will be replaced by a semi-autonomous system controlled by

Rail Car Configurations



an overseer. As such, the vast majority of construction, mining and industry will be carried out without direct human involvement. Instead, supervisors will give top-level guidance to a semi-autonomous system and work to further automate menial or repetitive tasks.

We foresee robots and remote-controlled systems carrying out almost all tasks on the surface: mining operations (particularly blasting); control of trains and rovers transporting equipment; installation of buildings and equipment; and moving equipment between the surface and the city through intermediate zones. These zones are intended to remove toxic perchlorate-containing dust and other contaminants. Many of the jobs traditionally carried out by entry-level human labourers will also be automated or robotically-aided[31] to some degree.

2.3 Production

Power generation in the completed Nexus Aurora colony is not significantly different from that in the early stages of colonization. The notable difference is the diversification of the power generation and storage infrastructure to safeguard against failure. We have also varied the number of technologies considered as a precautionary measure against any one energy production method becoming significantly more or less viable in the 80 years from today to the completion of the project. In practice, Nexus Aurora will use some blend of these generation techniques with exact numbers determined by the colonists. The total power demand of the base is estimated to peak at 10 GW, with the vast majority of that needed for the production of materials for construction.

Nuclear power is our primary plan for power generation in the later years of the colony, as it removes the need for storage. The most suitable architecture for our purposes is CANDU, as it operates with low-purity uranium, has many passive safety features and does not require large pressure vessels to be manufactured. Providing 10 GW using purely CANDU reactors would require approximately 1400 tonnes of unenriched uranium per year, which can be imported or mined in-situ. The primary concern of a nuclear power system on this scale is cooling - radiator arrays would have to span around 20 km^2, including buildings radiating heat.

Ground-based solar energy remains highly effective, scalable, and resilient against failure. Manufacturing lightweight, high-efficiency photovoltaic cells on Mars is not practical due to the complex production process, so heavier and less efficient arrays will have to be deployed in greater numbers. One-axis tracking is also very promising for increasing output. To fully power the city in this way, roughly 300 km^2 of solar farms would be required.

Space-based solar systems with power beaming are very promising, as they provide power almost around the clock with virtually no storage required. This technology is still in its infancy, so it is hard to design for and thus we have not planned to rely on it.

Power storage needs can be reduced by running power-hungry industrial processes only during daylight hours, but around 100 MWh of capacity will still be needed as backup for essential systems. Sodium-sulfur is the most promising battery chemistry, as it has high density and the electrolytic chemicals are both abundant on Mars. Mechanical storage, such as flywheels or hydroelectric, does not have anywhere near the energy density required.

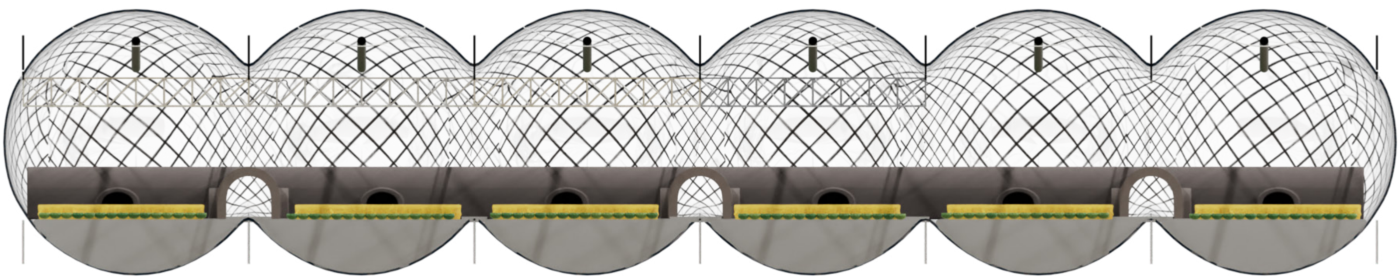
Farm buildings take largely the same form as habitats (utilising the BFRP tubes) but the major difference is that much of the later-stage farming complexes have been moved north, to a massive farming outpost, in order to increase received light throughout the year. More detail is given later in this report.

Apart from gradual upscaling as the colony grows, production processes of water and air are largely unchanged, although water production demands have increased with both industry and habitation. The glaciers in the region of Hellas Planitia are of such great scale that they will practically never be exhausted. Current estimates for the size of the glacier that exists within kilometres of our landing site is 2-5 km^3, an order of magnitude greater than the requirements for Nexus Aurora.

The biopetrochemical and electropetrochemical industry remains a linchpin of the economy of Nexus Aurora. In addition to the colossal demands of tens of thousands of tonnes of polymer for the construction industry, polymers provide a major export. As the production scales, larger and more efficient chemical processes become practical. This reduction in energy cost is the primary driving factor that allows the colony the luxury of large open domes and towering landmark buildings.

Mining in Nexus Aurora, as with all other industries, takes place on a colossal scale to keep up with the pace of expansion of the city. Raw ore and basalt demand is estimated at 2 million tonnes per year. Given the scale of this demand and the hardness of the rock in our region (basalt is typically 6-7 on the Mohs scale), industrial explosives are required. Two quarry sites north of the city have been identified for producing basalt (needed for basalt fibre and iron) and plain regolith (needed for soil for farming, rammed soil blocks, among other uses).

A major industrial zone for Nexus Aurora has been planned inside Geim Crater. This area is shielded from both the colony and mining areas and is situated at an



170K Farm section

intersection in the rail network, ideal for both importing and exporting material. This holds the production facilities for almost all heavy industry. Steel, basalt fibre, polymers, sulfur concrete, cement composite and many other less-used materials are required. They will be processed with rolling mills, composite layup machines and casting equipment. Light manufacturing of consumer goods and other small-volume chemical products is largely completed inside Nodes to enable people to work close to their homes.

2.4 Medical

Nexus Aurora will model a medical system that provides accessible healthcare for all citizens. We can derive a large portion of the Mars-based medical system specifications from what is accepted to be the medical standard on Earth, and from medical knowledge of living in low Earth orbit. The details of medical standards are largely omitted from this document, which instead focuses on facets of health and medicine unique to Mars.

Life on Mars carries a number of health risks: hypo-gravity may decrease bone density and immune function; solar radiation exposure can cause cancer at higher rates of incidence and severity; isolated lifestyles can degrade mental health; risk of depressurisation events threaten barotrauma and “the hurls” (depressurisation sickness); and several others. A heavy focus will be placed on these Mars-specific ailments, each with a dedicated outpatient centre for both treatment and research.

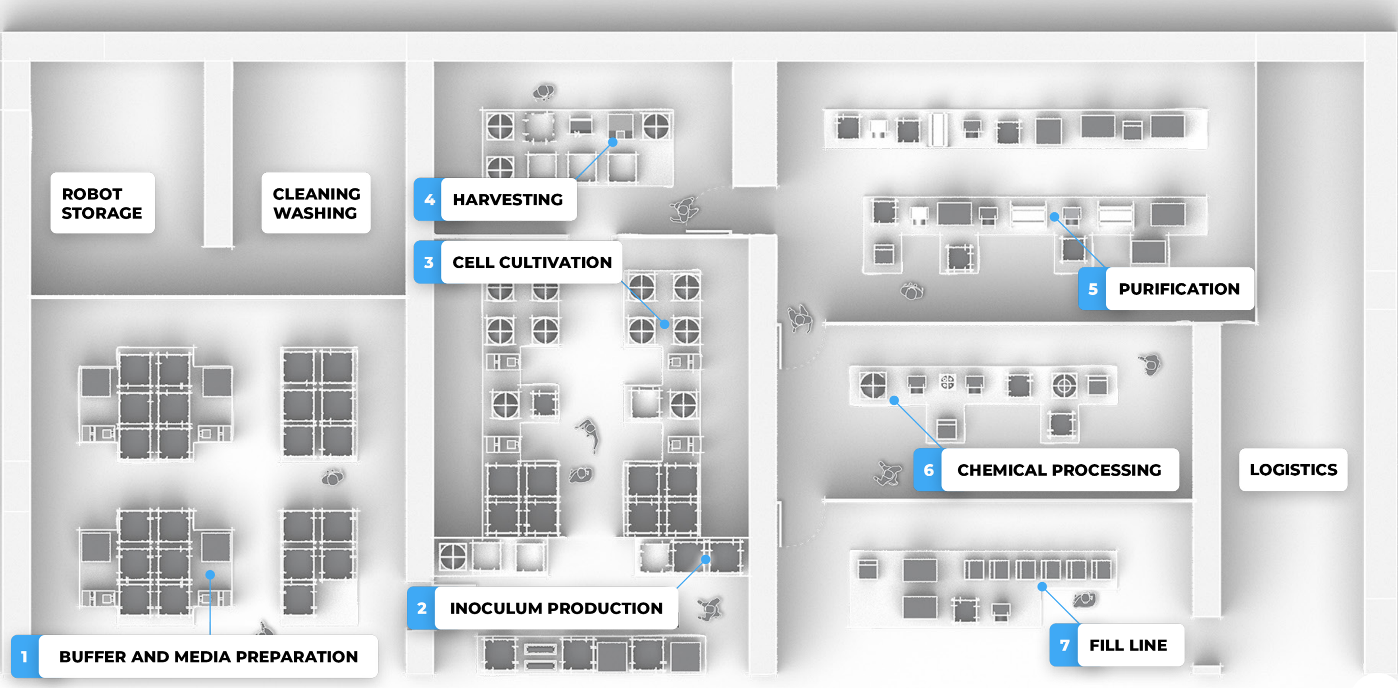
The means of travel will often be limited on Mars, necessitating an increase in the widespread accessibility of medical services. To remedy this, we have designed a network of conferencing equipment dedicated to medical triage (referred to as tele-triage). Patients can securely video conference with an on-call triage nurse from a public tele-triage station, and the nurse will typically provide instruction to the caller, such as which health care provider to visit. Patients can call in with their personal devices or access public access stations, which will be strategically placed throughout the colony, especially in remote and high-risk environments such as mining quarries. While telemedicine is possible with this system, it is not intended to replace in-person medical visits. Rather, it exists primarily to reduce unnecessary hospital traffic and provide triage staff with a powerful logistics tool.

To serve the medical demands of Nexus Aurora, we have prepared facility designs for 3 large hospitals (each with a roughly 750-bed capacity), several buildings dedicated to outpatient specialties, and around 100 clinics of varying sizes. All clinics will be public, and all specialty beds found in clinics and outpatient buildings will be counted as ICU/specialty beds made available for hospital overflow purposes. With these facilities, we target a total medical capacity of 4000 beds.

The potential for depressurisation events imply some likelihood of hermetic lockdowns in which people can become stuck in certain buildings or corridors. As the requirement of hermetically sealing doors nullifies the logic of egress regulations, we design each hermetic segment in the city to include standardised emergency medical kits so that trapped people will never be without access to medicine. Near each medical kit will be a tele-triage conferencing system to reach emergency responders and medical staff.

Manufacturing pharmaceuticals on Mars will be critical to the sustainability of the colony. While importing pharmaceuticals from Earth is possible and will remain a viable source, there is no financial substitute to manufacturing these drugs. Due to the lack of chemical feedstock, we have deemed a biomanufacturing approach to be superior. This requires less energy and can produce a wider variety of products than a chemical production line[32]. To this end, a modular medicine production platform has been designed to allow a scalable, flexible production line.

This system was illustrated with a production system for salicylic acid, a widely used drug and chemical precursor. Genetically engineered E. coli[33] and perfusion cultivation[34] are used to produce high yields with little equipment and waste. This system has been modelled to fit multiple



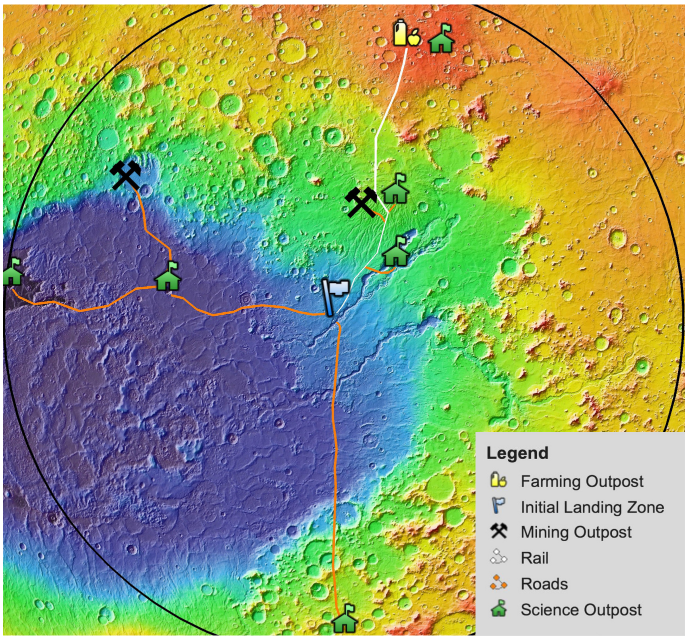
Modular Medicine Production Line

production lines in a single 570Hab, along with support facilities such as quality control and water purification through reverse osmosis. Logistics robots carry out much of the work of moving material and equipment around the facility. A single production line with a footprint of around 1200 m^2 employing 40 technicians and scientists[35] can produce salicylic acid at an average rate of 55 kilograms per day. 36 of these production lines are sufficient to produce the 58 most-consumed drugs from WHO's Essential Medicine list[36].

2.5 Beyond The City

Beyond the dense urban center of Nexus Aurora and the outer ring of quarries and solar farms, human presence in Hellas Planitia reaches far across the landscape. A number of small scientific outposts, at various points of interest identified from orbit, are planned, as well as small mining projects near expected mineral deposits. We anticipate the placement of many more of these mining projects as in-situ analysis detects deposits of valuable minerals such as lithium and copper. We also envisage a limited number of outposts far from the city for purely tourism or sightseeing purposes, although these are harder to justify economically.

Outpost locations



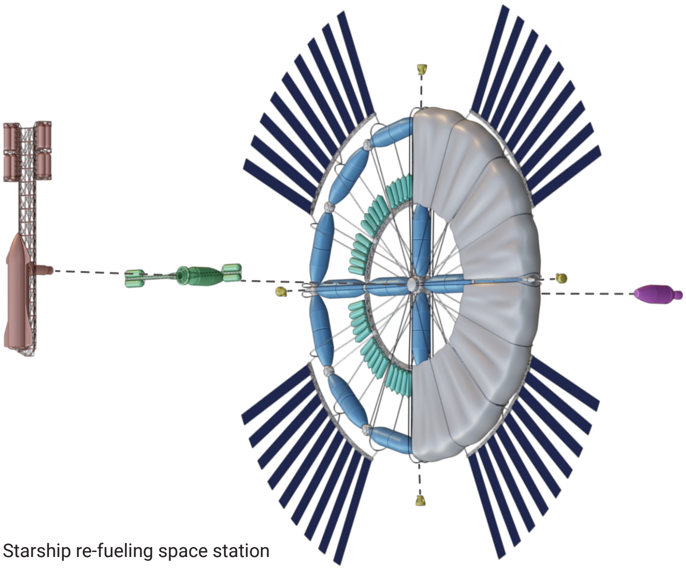
The planned scientific outposts are located in sites of particular geologic or geographic interest. For example, the confluence point of Niger and Dao Vallis is an excellent point to find deposited sediment, and Nidavellir Point, which is located at the lowest point on Mars, ideal for deep-crust geology and potentially even astrobiology.

Mining outposts near Cañas crater and Terby Crater have been identified, as orbital data suggest that concentrations of hydrogenous minerals, sulfates, and ferric oxides are significantly higher in the regions close to the city.

However, the scale of these specialist mining and science outposts pale in comparison to Calorie Outpost, a sub-city located 1030 km north of Nexus Aurora at a significantly higher altitude in Tyrrhena Terra. Moving the majority of the farming far north is advantageous. Increasing light during winter is a massive boon for farming, as it reduces the amount of food that needs to be stockpiled for winter when productivity is lower, unless we resort to the power-hungry method of artificially lighting hundreds of square kilometres of land. This will reduce the number of farms that need to be built.

Calculating this reduction factor is multivariate, but our best estimates are that moving farms to the north reduces the land area needed by around 45%. This represents a colossal decrease in energy demands for population growth, even when considering the additional cost of building and operating a rail line to connect Calorie Outpost and the main sections of Nexus Aurora. For this reason, the decision to move farming north comes easily.

Part of the economic role of Nexus Aurora will be to support a significant manned presence in low Mars orbit. At a minimum, this orbital outpost would just be a refuelling station for outbound Starships. It will use solar power to convert water and CO^2 from asteroids and the Martian moons into fuel with the Sabatier process. However, this fuel station could well expand to a fully fledged orbital city with habitation for thousands of people, orbital manufacturing, and provisioning for spacecraft travelling between Mars and the outer solar system.



Starship re-fueling space station

It is hard to predict exactly how much orbital infrastructure will be needed, because it is heavily dependent on the amount and nature of deep-space development elsewhere in the solar system. We have made plans for a basic habitation and refuelling station, which can house a few hundred people in a rotating ring, protected from radiation by a layer of asteroid regolith and ice enclosed in a Kevlar bag. If and when the orbital station expands, it could either do so by enlarging this station (by adding additional counter-rotating rings, or increasing the radius of the existing ring) or building additional stations in similar orbits.

In addition to large stations in Martian orbits, the connectivity needs of the colony are addressed by an array of communication satellites. Earth-Mars links are provided by a number of high-orbit satellites with 20 m dish EHF links, each providing 9 Gb/s. Communication to the Martian surface is done with X-band radio to large ground stations, with fibre connections connecting to ground-based data centres and consumers.

3 LIVING IN NEXUS AURORA

We have explored many creative methods of engineering a city for 1 million people. However, it is equally important to create a city that 1 million people will actually be comfortable living in. Since the city is designed for permanent residence, it must be appealing enough to motivate people to leave their belongings and loved ones behind forever and begin a new life on Mars. This requires titanic efforts in architecture, sociology, urban planning and macroeconomics to make Mars not only a place where people can live, but where people want to spend their lives.

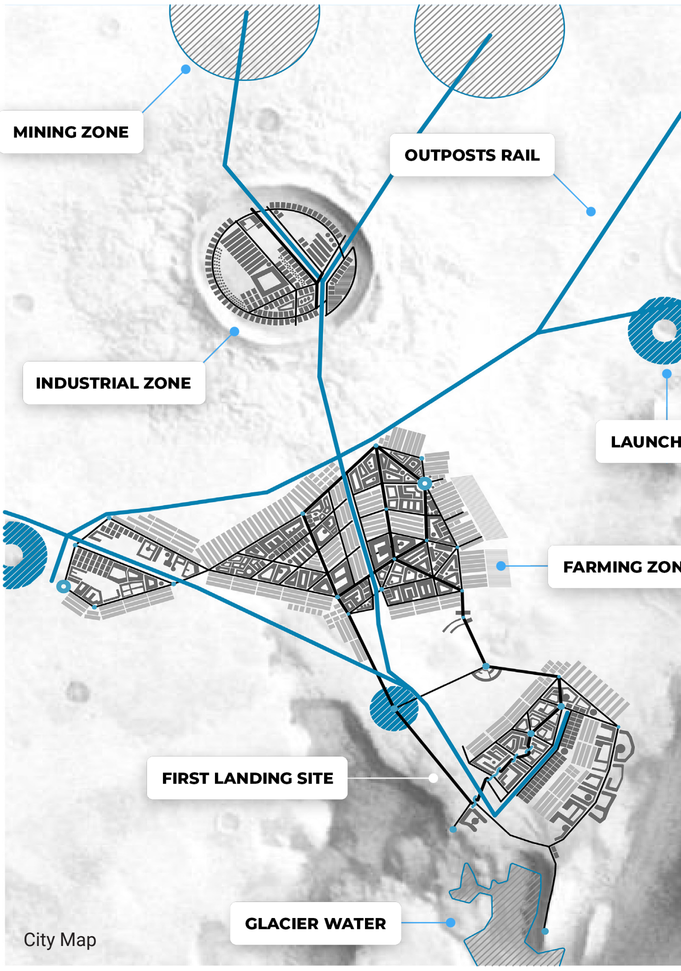
3.1 Urban Planning

The challenges of urban planning on Mars are extreme. It is difficult to create a living system where inhabitants can flourish given the necessary physical restraints of Martian life. The solutions to these problems come from innovative applications of existing concepts in urban design theory, married with creative uses of the structures available.

The top-level layout of the city is modelled on Howard's Garden City concept[37]. It avoids sprawling urban cores in favour of distributed small towns, with employment scattered both in these towns and in dedicated industrial hubs such as the Geim Crater complex and launch complexes. Each of these "Nodes" is organised around a central open space, generally a 200 m dome embedded in a natural crater. However, long, thin spaces built into lava tubes are also an option. Large areas of housing, both in smaller 570Habs and Air Mattresses, provide neighbourhoods of 10-15 thousand residents, interspersed with zones for employment. The Nodes differ in size depending on the differences in land value between more and less desirable areas, without creating low-value segregated areas.

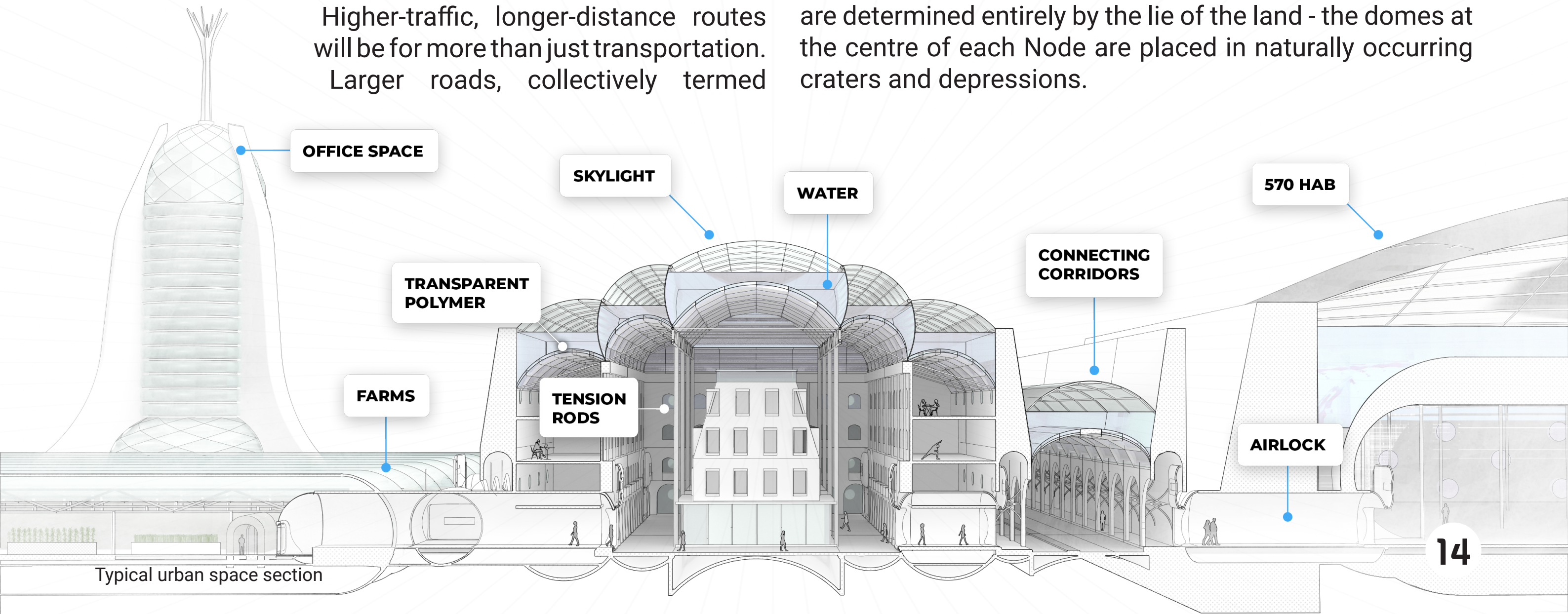
Intra-town transport is provided depending on traffic levels. The shortest or quietest routes are composed of service tubes which are 6 m in diameter and contain multiple levels: a pedestrian walkway, service tubes for robots, and passages for water, power, and air distribution. This type of tunnel can also be fitted for indoor light rails, which are used for higher-traffic transport along longer distance routes.

Higher-traffic, longer-distance routes will be for more than just transportation. Larger roads, collectively termed "boulevards," have been developed to contain multiple features. This will include: pavements for pedestrian traffic; wide roads for autonomous cargo transport, bicycles and bus-style vehicles; and in the busiest areas, ample shopfronts. The intention is that almost all routes over 50 m long will be boulevards, making the city supremely walkable and bikeable. Unlike car-focused American suburbs[38], the transport areas will be more like European high streets that act as areas for congregation.



City Map

On a larger scale, the zoning of the city is focused on following major transport lines to allow easy movement of people and equipment. The roles of Nodes vary across the city, adapted to the various industrial regions. For example, we have mapped out a large industrial zone in Geim Crater, and a region dense with nuclear power generation near Leeuwenhoek Glacier. The exact locations of these Nodes are determined entirely by the lie of the land - the domes at the centre of each Node are placed in naturally occurring craters and depressions.



Typical urban space section

The character, culture and architectural style of each Node varies according to the preferences of the inhabitants. Nexus Aurora will provide the tools for citizens to shape their habitat into a home. The available areas for personalisation include the architectural styles of buildings within habitats, street furniture (including trees, which will be a feature of almost all streets), and the form and function of communal buildings.

A multi-purpose NFC card can be used for many purposes such as access, ID, and contactless payments. It allows for streamlined access and services across the city. Within the city, all restricted access, private or industrial, is controlled by NFC card authorisation. This allows for anonymous monitoring of travel across the entire colony, which is a valuable tool for optimising traffic flow and emergency response. NFC card access is also useful for ensuring security and peace of mind. However, the implications for the creation of a surveillance state are severe, and a number of anonymous protocols have been developed for preventing unscrupulous governments or bad actors from harvesting personal data.

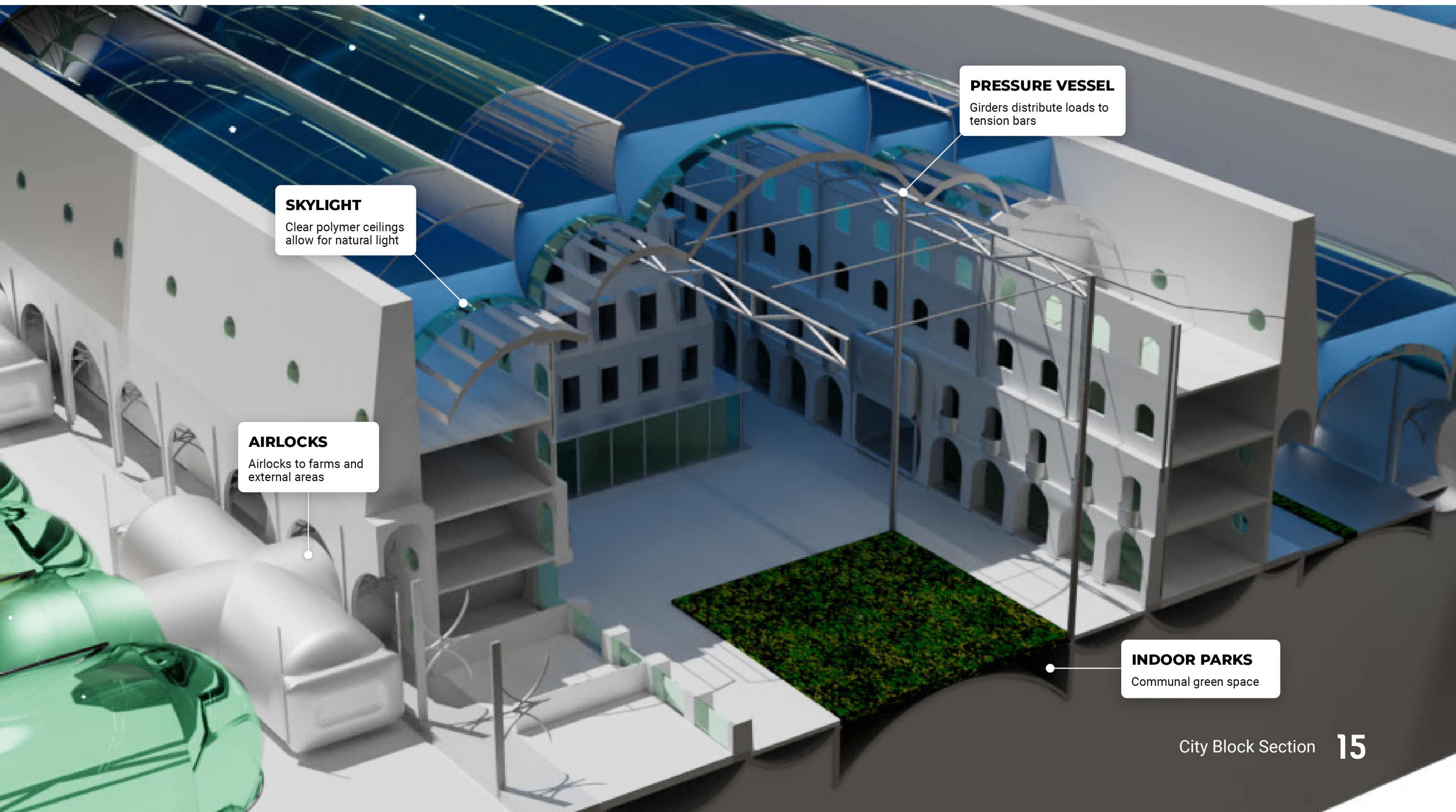
3.2 Character of the City

The cultural character of Nexus Aurora is shaped by its people. By 2100, we have estimated that 95% of the city's population will be Earth-born. We have attempted to identify which Earth regions will send the most migrants to Mars based on socioeconomic factors. We predict that the largest populations will be from the Anglosphere (around 30% of immigrants), East Asia (20%), and South Asia (15%). We will have no nationality-based selection criteria for immigrants to Nexus Aurora, so the city will be a cultural melting pot.

Great effort will be made to allow citizens to preserve their cultural identity. Each Node will have a designated second official language, alongside one of the three main languages of the colony which will be determined by census. Citizens will be encouraged to style their homes and streets according to familiar design practices from Earth. This will allow communities to shape their communal spaces, determining the form, usage and nature of parks, recreation areas, and places of worship. The form and function of street furniture like statues, benches, and street markets would also be open to the discretion of communities, with common rules to prevent offensive statues or art being installed.

The nature of urban design in Nexus Aurora produces natural communities of all scales. The city has pressure-tight dividing barriers, creating blocks of a few hundred houses, each with small amounts of shared open space. Clusters of a few dozen 570Habs and houses within Air Mattresses are formed between boulevards, with populations of a few thousand sharing amenities like shops, parks and community halls. These then fit into neighbourhoods (sharing schools and places of worship) and Nodes (with communal open spaces). This emphasis on fractal communities is to avoid feelings of isolation and to provide citizens with a real sense of belonging in their homes.

A vital part of community engagement is sport and recreation. This is key for increasing inter-generational and inter-household belonging in the entire city, while promoting physical and mental health. The recreational needs of a city of 1 million will be functionally equivalent to that of an Earth city. Bars, community centres with nightly activities, plays, cinemas and sports arenas have all been considered essential parts of life. Any indoor spaces with no specialist structural needs (such as bars and cinemas) can be built into the Air Mattress with no difficulty. These buildings will be scattered throughout the city on "high streets" within the residential areas and along Boulevards to create gathering points near homes rather than isolated in retail parks.



City Block Section

There are a few activities limited by the size of pressurised volumes - arenas for pitch sports like football and rugby are difficult (although possible in Node domes), so court and track sports like tennis, basketball and running should be emphasised for live spectators. The Mars-specific needs of the community are near-impossible to predict; open spaces to remind the city dwellers of Earth are strong candidates, so urban planning has emphasised the inclusion of parks. Additionally, the long distances of urban farmland make running, walking and cycling possible, so radiation-shielded walkways have been added to all farms for this purpose.

The family unit is at the core of the community, no matter the demographic or type of family. The architecture of the city provides private apartments for each family with space for bedrooms, a kitchen, bathroom and sitting room. These “standard-issue” apartments are comparable in size to city apartments on Earth. While they are not overly spacious, they are a comfortable place for a family to call home. Apartments will be owned, not rented, so citizens can decorate and modify the spaces within building regulations.

While diversity is celebrated, we also recognise that unwanted prejudices, biases and bigotry will travel to Mars as well. The first method for mitigating such issues is education. As part of their permanent induction to Nexus Aurora, new citizens will attend a small-group style teaching programme which will contain content on directly tackling and subtly subverting existing prejudices. Secondly, community action and coordinated enrichment aims to prevent the formation of exclusionary communities. This includes cultural exchanges between Nodes with large cultural groups, inclusionary festivals and all-ages education programmes to proactively counteract tensions. An array of measures will also be taken to prevent active discrimination. This includes anonymised recruitment and performance review practices across Nexus Aurora, colony-sponsored immigration for highly skilled individuals without the funds to travel from Earth, and active engagement between community advocacy groups and government to allow any issues to be raised.

3.3 Economics

Building a strong economy for Nexus Aurora carries many broad-stroke similarities to projects in contemporary international politics and macroeconomics. It is important to distribute the economic benefits of growth among both societal and corporational interests while minimising the chance and effects of economic depression. The overarching goal of the fiscal plan of Nexus Aurora is to achieve self-sufficiency from terrestrial economics, which is to minimise investment tying Martian policy to the interests of groups on Earth, and a neutral or even positive trade balance.

There are no precedents for building an economic system for Mars that can be simply adapted for Nexus Aurora. Rigid shipping times, a hostile environment requiring high welfare, long payback time on investments and a deep political involvement in the economy means that a historic economic model cannot be simply adapted.

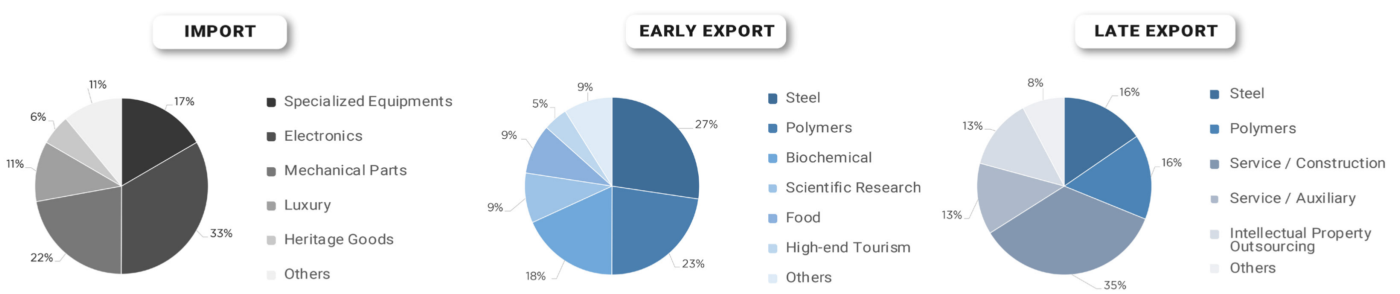
The early stages of Nexus Aurora will be in deficit - a colony of tens of thousands can produce almost nothing to offset the large cost of shipping production equipment to Mars. Small income streams may exist, such as high-value tourism or scientific research, but the colony will run at an enormous loss for decades.

To fill this gap, investment from private and public groups on Earth will be needed. This will primarily include national governments, large firms and private individuals. In this early stage, all investment will be quantified and unified into a national bond system. This minimises the undesirable political entanglement from non-monetary investment, a strategy commonly employed in neo-colonialist enterprises[39]. The incentive for national governments providing this investment is the fact that almost all of the initial funds will be spent on manufacturing and engineering on Earth, essentially turning investment in Nexus Aurora into a national jobs programme.

During later stages of Nexus Aurora, the national government will aim to buy back these bonds from terrestrial investors. This holds multiple benefits: investors willingly hand in holdings on Nexus Aurora, and the potential for significant returns will further incentivise investment in the project. It also provides a “carrot and stick” for groups not adhering to government policy, by freezing buyback of stocks controlled by such groups.

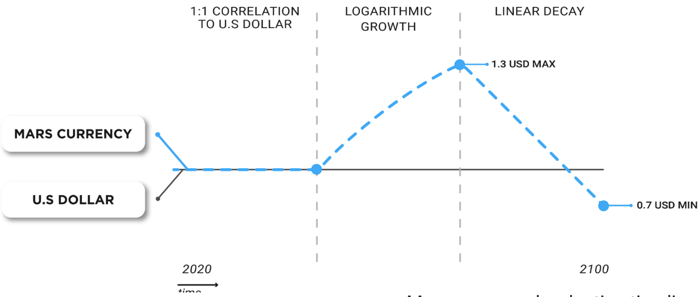
In the long term, a solution must be provided to account for the huge initial trade (and thus economic) deficit. We feel the optimal solution to this is a long-term strategic policy of currency devaluation. Having a slow reduction in the effective value of Martian currency allows cheaper imports in early years while making exports competitive in the later stages. This scheme has diminishing returns as other colonies use the same strategy, which makes Nexus Aurora competitive with other colonies as other organisations develop cities of their own, which will also serve to make our export strategy significantly more lucrative.

In the long term, the trade balance of Nexus Aurora will be the following. Imported products will primarily be vital engineering components, luxury, and heritage goods. The bulk of exports will be to other Martian colonies[40], with



Financial import-export charts

some exports also to outposts elsewhere in the Solar System (Mars' decreased gravity and thin atmosphere make launching material much easier than on Earth).



Mars currency devaluation timeline

We have come to the conclusion that it is neither possible nor beneficial to prevent other major powers setting up Mars colonies. On the contrary, we should encourage this. Trade with other locations on Mars does not carry the prohibitively expensive launch costs of Mars-Earth trade, and the same launch costs mean that materials can be sold with a significant markup (which are slightly less than shipping costs) and a significant market will still exist. As such, the most exported goods will be those needed in the largest quantities by other colonies, and those that Nexus Aurora can produce most effectively: food, polymer composites, and steel. Secondary physical exports will include products that Nexus Aurora can produce in greater quantities and at lower prices than other colonies: pharmaceuticals and biochemical products.

However, the most lucrative economic sector of Nexus Aurora is the services industry, particularly intellectual property and quaternary-sector services. The concentration of both highly educated workers and technological development will, as with Silicon Valley before it, be a fertile breeding ground for development of technologies and products with markets across the solar system. Tertiary- and quaternary-sector exports have the additional advantage of not requiring transport to Earth.

The internal economics of Nexus Aurora will also shift as it grows from an industrial and research outpost to a full-fledged city. To facilitate innovation and attract immigration and investment to the colony, we intend to encourage partnerships with both Earth-based and Martian companies to create a free market for goods and services for the citizens of Nexus Aurora. However, this market will require new regulatory structures to adapt to the peculiarities of the Martian economy.

The most prominent such structure is the formation of vertically-integrated consortiums of similar businesses, which serve to stabilise the prices of goods and services against demand shocks and provide a streamlined method of regulation. To deter cartel formation, the Martian government will have tight regulatory control over the foundation, role and internal hierarchical structure of consortiums. This creates de-facto nationalised industries while still allowing free market competition between firms within each consortium. One example of this regulation is servitisation of many products, especially those shipped from Earth, to ensure smooth delivery and support of all equipment.

Another difference is the existence of a level of state-provided welfare considered radical for Earth, to ensure the indefinite welfare of the citizens and to prevent various dystopian "oxygen fees apply" scenarios. This takes the form of a system of pseudo-UBI, where the basic needs of citizens (life support, basic food) are provided by the state rather than with cash. This is backed up with a price ceiling on certain goods, to prevent profiteering by private firms.

Beyond these economic activities, there is one lucrative source of income of note: the influx of new colonists. It is assumed that the vast majority of colonists either pay for their own passage to Mars (either directly, in the much-touted "sell your house, move to space" model, or via sponsorship by an employer or nation). However, it takes a small number of individuals paying for a premium experience on Mars - either short-stay tourists[41] or wealthy individuals hoping to buy a more luxurious trip and home in Nexus Aurora - to completely offset the diminishing cost of shipping and technology procurement.

Managing this entire system of welfare is the Martian Sovereign Wealth Fund. Modelled on similar funds in countries like Norway and Singapore, this organisation is funded by exports from centrally-owned industries such as food and basic construction materials. It is used not only to procure these necessities of life, but to perform the bond buyback described above.

For the incomes and outgoings of the government of Nexus Aurora, costs remain high in initial years, driven by the massive import of industrial equipment. However, this is increasingly offset by profit from export, tourism income, and taxation. Assuming that it began in 2020, Nexus Aurora is profitable by 2100, but will take several further decades to balance the colony's debt, with bond buyback leading to true fiscal independence.

It is important to note that economic and pseudo-economic factors have been of utmost importance in almost all decision making in Nexus Aurora. The drive to reduce mass and energy consumption has been critical in our structural designs, with the ultimate goal of reducing mass shipped from Earth.

3.4 Administration

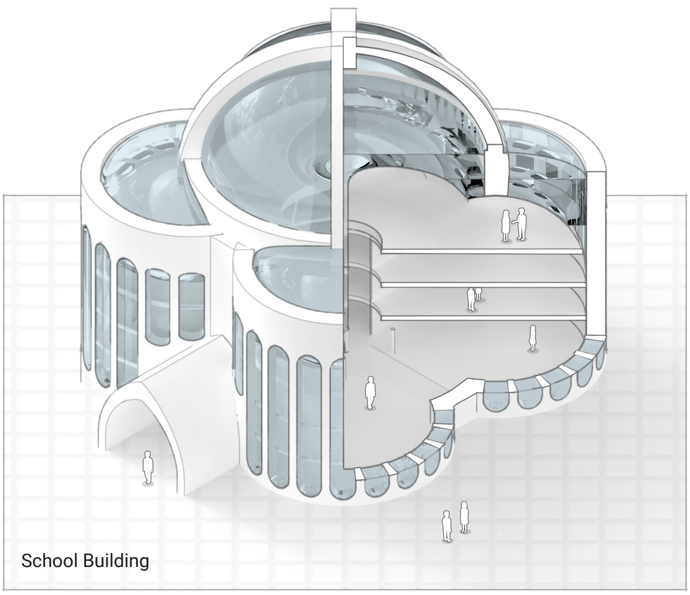
In the broadest sense, a system of government is a bureaucratic structure that serves the inhabitants of the community. Nexus Aurora represents an opportunity to develop a more empathetic, coherent framework around the lives of citizens. We aspire to be optimistic but not utopian, and acknowledge the need to have a mutable system that can be improved by the changing needs of the population. As such, we have set out the goals and specifications of political, education and judicial systems according to the overarching ideals of Nexus Aurora.

The ultimate goal of the government of Nexus Aurora is the preservation of the rights of Mars inhabitants, both to their personal rights and the right to collectively shape the future of the community. While we cannot foresee every future challenge facing Nexus Aurora, we have outlined several potential pitfalls and made provisions in the governmental structure to avoid them. In brief, it is an open, representative democracy backed by technical advisory groups providing stability and informed decision making for the good of the city.

One particular risk is the formation of collusive oligopoly: corporations on which Nexus Aurora is dependent, particularly Earth-Mars shipping, can form cartels that can strongarm the elected government into developing financial interests above the interests of citizens. To prevent this, it is vital to ensure that companies are competing in a fair and open market for the considerable business that Nexus Aurora can offer.

The keywords of the government structure are accountability, transparency and cooperation. These are all essential elements when any power structure is in possession of life-or-death power over citizens. Citizens must be able to trust that elected officials are working in the best interests of the community. The following methods are in place to assure this: frequent referenda; career term limits for politicians; accessible meetings; and a completely open public record of decision-making. The following precautionary methods are in place should a particularly divisive leader take power: inflexible limits on the conduct and spending of elected officials; required approval of certain decisions from subject-expert advisory groups; and a multi-stage system of checks and balances on all significant acts.

The education system is of prime importance. The foundations of Martian society are built upon research, a desire to explore the unknown, and the need to build future generations with the skills needed to thrive in such a unique environment. The education system aims to import the most effective parts of Earth theories allied with specialised developments to fit the needs of Mars.


School Building

The educational system for citizens aged 3 to mid-20s aims to break from established doctrine of linear, test-based progression[42] between educational stages with little emphasis on practical life skills. Instead, students learn on mixed-age campuses in purpose-designed buildings, with classes organised into broad developmental tiers. Progression occurs not on a fixed-time basis but when students demonstrate mastery of relevant skills, via exams, coursework or capstone projects. Mixed-age groups encourage cooperation and respect and make use of student mentoring schemes to develop the skills of both learner and educator[43].

Within schools, there is an increased emphasis on practical as well as academic subjects. This includes technical skills (programming, mechanical maintenance), interpersonal skills (presentations, debating, teamwork) and practical skills (emergency preparedness, sign language for use in EVA suits).

Schools will provide ample work-life experiences to smooth the transition from education to profession. The primary method is internships (especially in high-demand professions[44] to fill these gaps without resorting to forced career routes), with school alumni encouraged to open their workspaces for current students.

The socio-economic and political environment of Nexus Aurora will not be perfect, but we expect it to mitigate many of the systemic conditions that lead to crime on Earth. Our environment will include a quasi-UBI system providing basic housing and food, a more comprehensive social security net, and increased regulation of imports of psychoactive substances. While this is not comprehensive, it is the beginning of an improved system.

The emphasis on criminal justice in Nexus Aurora is on restorative justice. This is both ethically preferable to punitive justice and imprisonment models, and removes the burden of a non-productive prisoner group on the colony. House arrest and community service models for all but extreme crimes facilitate reintegration into society and reduces recidivism[45,46]. When harsher prisons are required, a Scandinavian model[47,48] of less punitive environments will be employed.

Outside of criminal justice, civil disputes[49] will be handled by community mediation and dispute panels wherever possible - courts will only intervene where absolutely necessary. Lawmaking will be handled primarily by the elected representatives, but approval from panels of judges, sociologists and psychologists will be required to evaluate the effect of new laws.

Life on Mars is fundamentally dangerous: dust storms, fires, depressurisation, and chemical leaks are but a few of the potential emergencies that may arise. Due to these dangers, proper disaster relief is essential to life in Nexus Aurora. Live risk assessments will be carried out by Joint Emergency Response Centres in all urban centres, which also coordinate mitigation, preparedness and response across various departments. Drills for various emergencies will occur semi-regularly and training will be a mandatory part of schooling to ensure citizen preparedness.

Diplomatic relations with Earth, other Martian colonies, and the rest of the solar system are a priority to ensure smooth flow of migration and trade. Immigration will be handled by a multi-tier visa system that includes both temporary and permanent residents. Cooperation between terrestrial nations, key stakeholders (private and industrial) and supranational organisations will occur at the highest level of Martian elected government.

4 OUR NEXUS AURORA

We hope this summary, while brief, properly conveys our vision for a bold future and the path for building it. These 20 pages barely scratch the surface of the work carried out by our phenomenal international team. Behind this report are over 100 pages of technical reports, proposals for economic and political systems, evaluations of existing technologies and brainstorms of new ones. We have created over 5 GB of 3D models, diagrams and renders of our civilization, and all the images in this application have been rendered by our team. Planning and discussion stretches over 60,000 messages from 50+ team members in a multitude of time zones. We have no intention of halting progress now. We were brought together by this competition, but development of these concepts will continue after it is over. We will continue building until the day humans stand on Mars, in a city that defies every force of nature standing before it, until we can truthfully say, “Mars is our home.”

4.1 Contributors List

Coordinators: Adrian Moisa (SpaceInstructor), David W. Noble (Marsorbust), Henry Manelski, Koen Kegel (koenikova), Kim von Däniken, jakobberg, Felix M. Müllner, Vikas, NLDukey, Elias Malak (EliTheDude), Sean Wessels, Mitchell Farnsworth, Mae Elizabeth, Sitanshu Pani, Sam Ross (document editor)

Administration: Felix M. Müllner, Hyeonseo Daniel Kim (tankat), HoospitalBall, einarhg, CertifiedDefaultToday, thefiendhitman, Zam, David Zühlke

Buildings: Jakobberg, Sean Wessels, Koen Kegel (koenikova), SK9, Sitanshu Pani, Apollo, Kosaki Onoder, Dr. Orion Lawlor

Economics: Hyeonseo Daniel Kim (tankat), Felix M. Müllner, Arxivist

Equipment: ukudaly, Will Coulson, Henry Manelski, Marco, CaliDToday, Ignis Cogitare, Sitanshu Pan, Max Jagiella, Cameron Rough, PiTim, Bryce Bornhorn, Il Ho Cho

Infrastructure: Arxivist, Tankat, Sean Wessels, Arxvisit, blakemw, Sitanshu Pani, Dr. Orion Lawlor, Hyeonseo Daniel Kim

Lifestyle: Sitanshu Pani, Henry Manelski, Sean Wessels

Logistics: Mitchell Farnsworth, Sam Ross, Henry Manelski, Zam, fredfredb3rg, questionablyhuman, agustin99, shalrath, thephatpeach, Pranav Kishan, Cameron Rough

Medical: Kim von Däniken, b.funkt, Sean Wessels, Mae Elizabeth, Apollo, Julian, Brooke Shepard, Liam Berry

Production: Peteware7, Felix, Sean Wessels, MikeGo, Mark Watt Ne, Mae Elizabeth, Henry Manelski, CertifiedDefaultToday, Dr. Orion Lawlor, Julian, deadlifts12, Kim von Däniken

Transport: Cameron Rough, Bilal, Jakobberg, Martin Eizinger

Urban Planning: Koen Kegel (koenikova), Sean Wessels, Olivier Rinfret, zen, JWFJWF, Sitanshu Pani, Il Ho Cho, Daniela Castro

Utilities: Jakobberg, Koen Kegel (koenikova), Michael Dealbert, blakemw, idyllicchimp

Arts and 3D Design: Vikas, yury2bcu, Sitanshu Pani, splinter_vx, DrQuandryPHDToday, Elias Malak(EliTheDude), Mihai Haceanu, Framps, somepoint_sound_derm, felix, NLDukey, Bobbbay, Sebash, Natron, Calvin, THEWILDOFFICIAL, Felix M. Müllner, Rory Hyland, Alex Doyi

4.2 Compiled References

Buildings

1) https://mepag.jpl.nasa.gov/topten.cfm?topten=10

2) https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19650016474.pdf

3) https://www.energy.gov/sites/prod/files/2017/12/f46/2016_Occupational_Radiation_Exposure_Report.pdf

4) https://www.fosterandpartners.com/projects/mars-habitat/

5) B. Soares, R. Preto, L. Sousa, and L. Reis, “Mechanical behavior of basalt fibers in a basalt-UP composite,” Procedia Structural Integrity, vol. 1, pp. 82–89, 2016.

6) https://www.livescience.com/radiation-mars-safe-lava-tubes.html

Necessities of Life

7) I. Repins et al., “19·9%-efficient ZnO/CdS/CuInGaSe2solar cell with 81·2% fill factor,” Progress in Photovoltaics: Research and Applications, vol. 16, no. 3, pp. 235–239, May 2008.

8) https://www.westinghousenuclear.com/Portals/0/new%20plants/evincitm/eVinci%20Micro%20Reactor%20NPJ%20M-A%202019.pdf?ver=2019-04-30-211410-367

9) https://www.mhps.com/products/gasturbines/lineup/ft8mp/index.html

10) https://www.nasa.gov/mission_pages/station/research/long_duration_sorbent_testbed

11) https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180007365.pdf

12) https://www.nasa.gov/pdf/683215main_DressingAltitude-ebook.pdf

13) J. P. Grotzinger, “Analysis of Surface Materials by the Curiosity Mars Rover,” Science, vol. 341, no. 6153, pp. 1475–1475, Sep. 2013.

Production

14) Schilt et al., Perchloric acid and perchlorates 2003

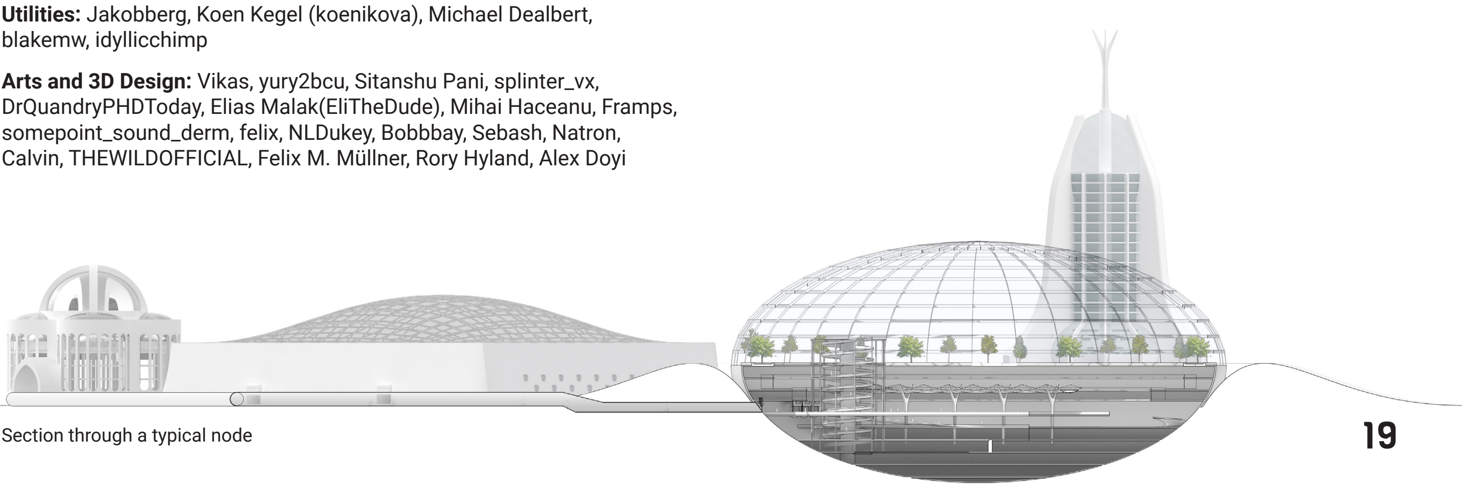
15) Salisbury, F.B., Growing Crops for Space Explorers on the Moon, Mars, or in Space,Advances in Space Biology and Medicine, Volume 7, pages 131-162, 1999, JAI Press Inc.

16) K. M. Cannon and D. T. Britt, “Feeding One Million People on Mars,” New Space, vol. 7, no. 4, pp. 245–254, Dec. 2019

17) https://www.eceee.org/library/conference_proceedings/eceee_Industrial_Summer_Study/2018/2-sustainable-production-towards-a-circular-economy/rethinking-steelmaking-zero-emissions-and-flexibility-with-hydrogen-direct-reduction/

18) https://new.abb.com/news/detail/54933/next-generation-electric-arc-furnace-stirrer-improves-steel-production-output

19) V. G. Luk'yashchenko et al., “Technology of Electric Melting of Basalt for Obtaining Mineral Fiber,” Journal of Engineering Physics and Thermophysics, vol. 92, no. 1, pp. 263–270, Jan. 2019.



Section through a typical node

Logistics

20) https://electrek.co/2018/08/30/volvo-new-electric-mining-vehicle-prototypes/

21) Y. H. Wen, H. B. Peng, D. Raabe, I. Gutierrez-Urrutia, J. Chen, and Y. Y. Du, "Large recovery strain in Fe-Mn-Si-based shape memory steels obtained by engineering annealing twin boundaries," Nature Communications, vol. 5, no. 1, Sep. 2014, doi: 10.1038/ncomms5964.

22) https://www.wired.com/story/amazon-warehouse-robots/

Structures

23) https://space.nss.org/settlement/nasa/75SummerStudy/3appendB.html

24) C. E. Hellweg and C. Baumstark-Khan, "Getting ready for the manned mission to Mars: the astronauts' risk from space radiation.," Die Naturwissenschaften, vol. 94, no. 7, pp. 517–526, Jul. 2007.

25) https://www.dsm.com/dyneema/en_GB/our-products/dyneema-fiber/dyneema-xbo-technology.html

26) Lhttps://www.nasa.gov/directorates/spacetech/niac/2020_Phase_I_Phase_II/lunar_crater_radio_telescope

Infrastructure and Logistics

27) Hall, R. and Shayler, D., 2001. The Rocket Men. Chichester: Springer, pp.49-51.

28) http://www.apics.org/mediaarchive//omnow/Crack%20the%20Code.pdf

29) https://www.ocadotechnology.com/blog/2019/1/14/experimenting-with-robots-for-grocery-picking-and-packing

30) https://www.ocadotechnology.com/blog/2019/1/14/experimenting-with-robots-for-grocery-picking-and-packing

31) K. Junge, J. Hughes, T. G. Thuruthel, and F. Iida, "Improving Robotic Cooking Using Batch Bayesian Optimization," IEEE Robotics and Automation Letters, vol. 5, no. 2, pp. 760–765, Apr. 2020.

Medical

32) M. Gavrilescu and Y. Chisti, "Biotechnology—a sustainable alternative for chemical industry," Biotechnology Advances, vol. 23, no. 7–8, pp. 471–499, Nov. 2005,

33) Metabolic design of a platform Escherichia coli strain producing various chorismate derivatives" | S. Noda, et. al., Metabolic Engineering 33, p. 119-129, 2016

34) E. Heinzelmann, "BioTech 2019 – ZHAW Waedenswil, 2 – 3 July 2019: Part 1 From Innovation to Technology Breakthrough," CHIMIA International Journal for Chemistry, vol. 73, no. 9, pp. 763–766, Sep. 2019

35) https://biotechnet.ch/sites/biotechnet.ch/files/aktuell/dateien/chimia_2019-9_singleuse-biotech_2019.pdf

36) World Health Organization Model List of Essential Medicines, 21st List, 2019. Geneva: World Health Organization; 2019. Licence: CC BY-NC-SA 3.0 IGO

Urban Planning

37) E. Howard, Garden cities of to-morrow, 1898

38) J. Jacobs, The death and life of great American cities, 1961

Economics

39) https://www.ft.com/content/9f5736d8-14e1-11e9-a581-4ff78404524e

40) https://forum.nasaspaceflight.com/index.php?topic=44411.0

41) https://planete-mars.com/an-economic-model-for-a-martian-colony-of-a-thousand-people/

Administration

42) https://www.researchgate.net/profile/Nissa_Dahlin-Brown/publication/255685603_University_Community_Schools/links/02e7e5202812dedd65000000.pdf#page=7

43) http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.157.2967&rep=rep1&type=pdf

44) https://eric.ed.gov/?id=ED477535

45) https://bja.ojp.gov/sites/g/files/xyckuh186/files/Publications/RAND_Correctional-Education-Meta-Analysis.pdf

46) https://www.unodc.org/documents/justice-and-prison-reform/18-02303_ebook.pdf

47) https://worldjusticeproject.org/rule-of-law-index/global/2020/Norway/table

48) https://www.kriminalomsorgen.no/information-in-english.265199.no.html

49) https://via.library.depaul.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=3268&context=law-review

NEXUS AURORA

Nexus Aurora is focused on open sourcing space colonisation! Our primary objective is to design a city for 1 million inhabitants on Mars. The entire project started after The Mars Society launched the Mars City State Design Competition. Since then, Nexus Aurora has been growing in scope and ambitions, empowered by an international team of more than 100 active volunteers and thousands of supporters from all over the globe.

50+ Projects

Experts from major industries such as aerospace, architecture, logistics and education have kickstarted 50+ active projects. The list of active projects is constantly growing.

20+ Leaders

We have over 20 domain leaders ready to orient you at arrival. They are top contributors themselves and are able to answer all your questions. Simply type your questions anywhere you can. You will get immediate feedback.

Constant Updates

Results are updated on reddit.com/r/NexusAurora. We have a growing volunteering VR development team. There's insane amount of activity. Join us if you want to make a dent in the fabric of spacetime!

Online Community

A big thank you to all the volunteers that have spent time and resources on this ambitious project!

nexusaurora.com • reddit.com/r/NexusAurora