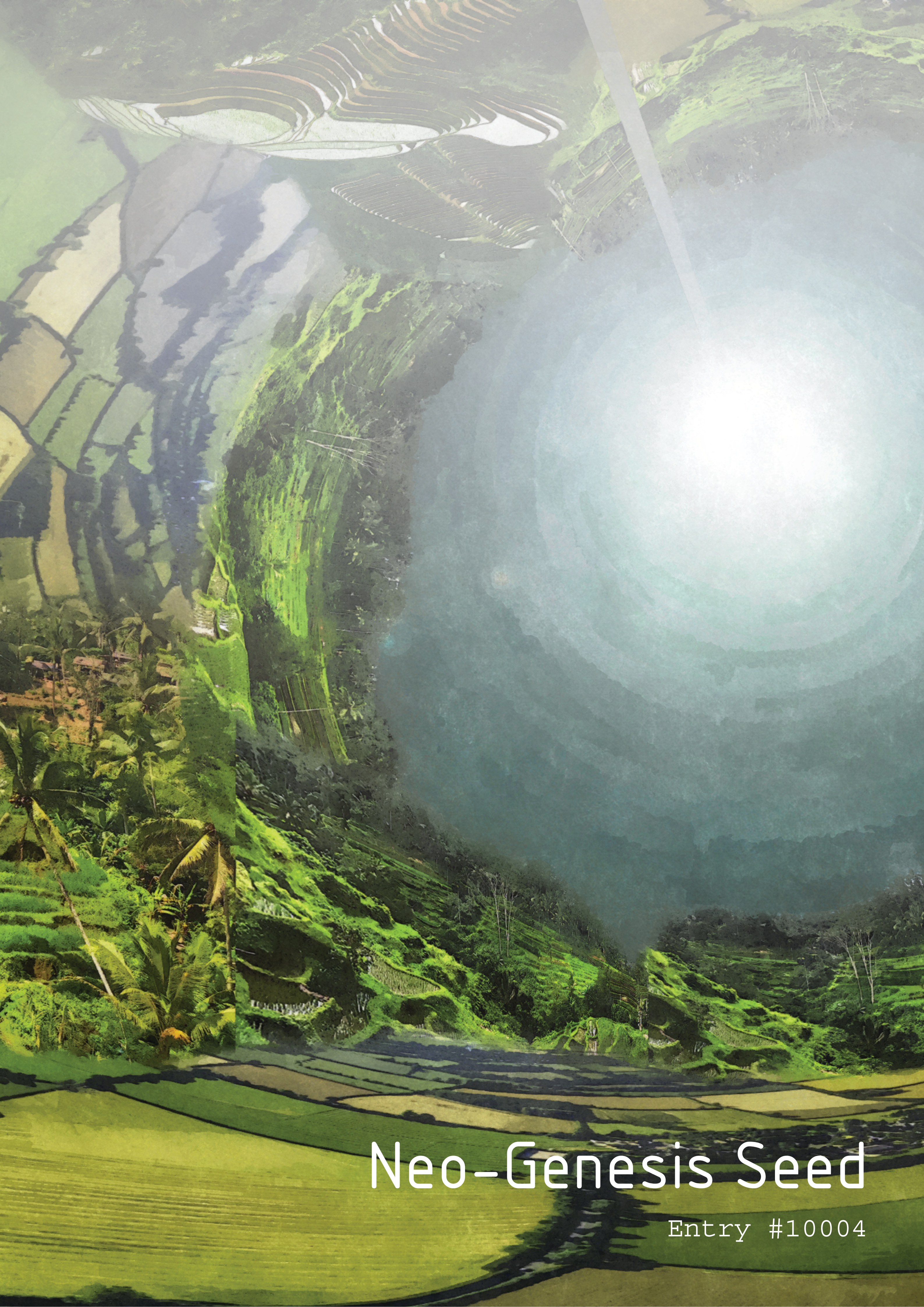

Neo-Genesis Seed

Entry #10004

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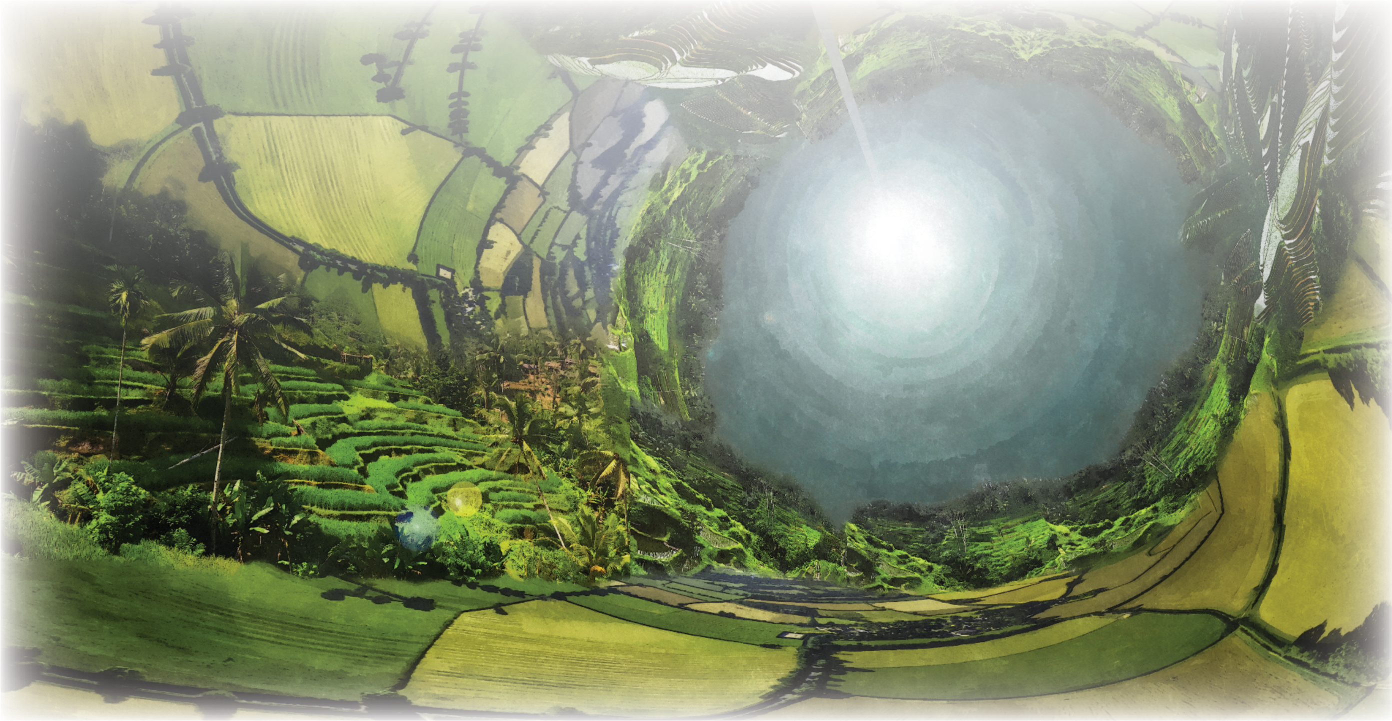


Executive Summary

Humanity stands on the cusp of interstellar expansion, and with it comes the unprecedented challenge of designing a self-sustaining society that can endure centuries of isolation. Neo-Genesis Seed is a generational starship—an autonomous, self-sufficient world that must function as a complete and evolving ecosystem, a stable social order, and a technologically resilient system. This document outlines a design framework that ensures long-term survival while fostering a thriving human civilization aboard an interstellar vessel.

At the heart of the proposal is the creation of an Earth-like environment within the ship. The vessel itself is designed as a rotating ellipsoid habitat with a radius of 1,000 meters and a length of 2,500 meters, large enough to provide a stable and regenerative ecosystem. The habitat simulates natural conditions with controlled gravity (1G at the outer edge), dynamic sunlight, wind circulation, and varied terrain to support biodiversity.

The interior is structured as an organic environment rather than an artificial enclosure, ensuring that natural cycles—such as air and water flow, soil microbiomes, and plant-animal interactions—can sustain life with minimal artificial intervention. A robust permaculture-based agricultural system integrates food production into the larger ecosystem, allowing for both human nutrition and the maintenance of ecological diversity. The goal is not mere efficiency but resilient overabundance, ensuring that natural systems can adapt and flourish over time.

A successful interstellar journey is not just an engineering challenge but a social one. The governance structure of Neo-Genesis Seed is designed to balance stability, adaptability, and public trust over a multi-century voyage. The governance system is structured as a council model, integrating representatives from occupational and administrative sectors to ensure decision-making remains decentralized yet cooperative.

Key to societal stability is addressing potential risks such as knowledge loss, power consolidation, and unhealthy population dynamics. Without an external support network, maintaining critical knowledge—both technical and cultural—is a paramount challenge. This is addressed through a combination of tacit knowledge transmission (apprenticeships, multi-specialization roles) and codified knowledge storage (durable microfiche and etched-glass archives).

Population dynamics are carefully managed, neither allowing unchecked growth nor risking long-term decline.

A target growth trajectory from 1,000 to 1,500 individuals over 250 years balances genetic diversity, workforce sustainability, and expansion potential upon planetary arrival. Crucially, this is achieved without authoritarian reproductive controls; in-stead, cultural and social incentives encourage balanced demographics. Unlike Earth-based civilizations that rely on vast supply chains, Neo-Genesis Seed must engineer for absolute self-sufficiency. This means selectively integrating technology that can be maintained, repaired, and reproduced by a small, closed society.

The approach rejects reliance on high-tech, fragile systems that require advanced industrial infrastructure. Instead, it prioritizes mission-critical transitory technologies (such as artificial sunlight and propulsion systems, which are needed only during the voyage) and sustain-able, low-complexity technologies that the settlers can maintain indefinitely. This philosophy applies to everything from agriculture (favoring traditional farming over automated hydroponics) to manufacturing (favoring tools and processes that require minimal technological dependencies).

Engineering solutions focus on passive, failure-resistant designs. Thermal regulation is managed via radiative cooling, humidity control uses passive condensation grids, and water is cycled using gravity-assisted hydrology. These systems minimize the need for complex mechanical components that could degrade over centuries.

A generational ship is not just a machine—it is a civilization in transit. This means addressing the full spectrum of human existence, including education, work, governance, and death.

Education is foundational, with a structured yet adaptable model ensuring that all citizens receive training in scientific literacy, ethics, and practical skills. A cultural emphasis on learning fosters long-term knowledge retention and discourages intellectual stagnation. Work is structured around multi-specialization, ensuring that no critical skill is ever possessed by too few individuals.

Even death is an integrated part of the ecosystem. Bodies are not waste but resources for learning and renewal. The cultural norm favors donating remains for medical education before returning nutrients to the habitat through alkaline hydrolysis, a process that recycles organic matter without waste. Ritual and remembrance practices ensure that death remains a respected and meaningful aspect of life.

Neo-Genesis Seed is not merely a spacecraft—it is a society designed to endure the most extreme test of human resilience: multi-generational interstellar travel. By prioritizing ecosystem integrity, adaptable governance, and sustainable technology, this proposal outlines a pathway to not only surviving the journey but arriving as a civilization fully prepared to thrive on a new world.

The success of such a venture relies not just on technical ingenuity, but on designing for long-term cultural and ecological stability. Through a combination of robust environmental design, resilient social structures, and pragmatic technological choices, Neo-Genesis Seed presents a compelling vision for humanity's expansion beyond our home star.

This is not just a ship—it is a world in motion, carrying a seed of humanity into space.

Assumptions

Fusion Power

An interstellar voyage designed to keep an ecosystem intact on-route requires a reliable, portable energy source that necessitates ordinary, stable fuel. It is the opinion of the authors that fusion power is the only TRL-2 technology that is reasonable to design for within the next couple hundred years.

Furthermore, while there are a handful of methods to generate energy from fusion, the most established and well-understood method is the steam thermal cycle generator. As such, this submission assumes that a thermal cycle generator will be used, complete with a turbo-pump to circulate the cooling water through a radiator array.

The most tested and well-understood method to convert energy from a fusion reactor into electricity is a traditional steam thermal cycle generator. In the context of an interstellar ship, this process would involve the fusion reactor heating the feed water into steam, followed by the steam being condensed back into liquid water inside a radiator array, finally returning to the fusion reactor as feed water. The pumping of the water can be facilitated using a turbo pump on the turbines, pulling feed water into the reactor. By tapping off the primary radiator output, a secondary radiator can cool the water further for use as coolant for the habitat's sunbeam. By controlling the throat diameter of the diverter after the primary reactor in tandem with the power of the reactor, the system can maintain efficiency without being completely shut off.

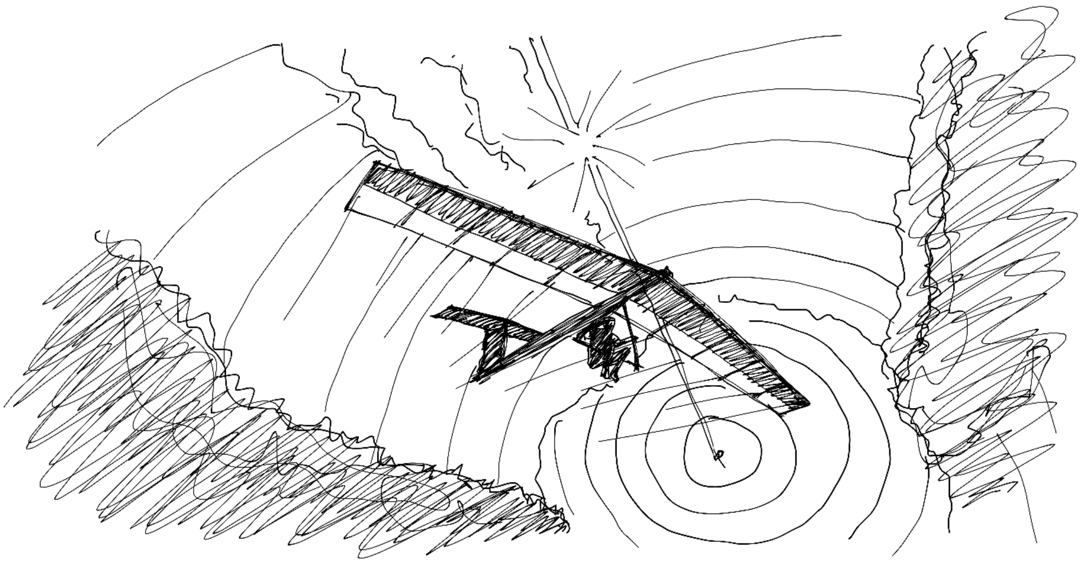
Single Mission

Considering that this competition is for the design of a singular vessel, and that the mission architecture is otherwise unspecified, this submission assumes that there will be no additional missions to the same destination for the purposes of redundancy, supply, or otherwise. This consideration has a dramatic impact on habitat design with regard to technology level, crew size, and knowledge retention. Furthermore, this goes for earth communications as well: this submission assumes no contact/information exchange between earth and the mission habitat.

Mission Born from Popular Altruism

Humanity's history is punctuated by periods of expansion for the purpose of opportunity and acquisition, often funded via the promise of trade. Over time, these expansion efforts have created a global network that touches every corner of the Earth, and will eventually do so across our solar system. The cohesiveness of this solar network is feasible because timeframes for travel and technology reliability are reasonable. Not so for interstellar distances. Numerous factors stand in the way of interstellar trade, primarily the duration required for travel and communication. Profitable and reliable trade cannot be expected when dealing with interstellar distances. By extension, human settlement missions sent to other star systems can't reasonably be considered an extension of the originating civilization and should be considered distinct civilizations without the possibility of material trade or resource acquisition.

Why then should such an ambitious project be undertaken in the first place? We propose that the only reasonable purpose behind interstellar settlement is that of popular altruism; that is, an altruistic goal of seeding humanity to the galaxy. It's very likely that this is only possible in an environment of economic and cultural prosperity and abundance. We imagine such a megaproject can only be attempted when most resources in the solar system are already tapped, the human population far exceeds that of the present, and most (if not all) people are reasonably well-off.



They said I was a natural. They were right. Most people were too intimidated by the initial acceleration to go through with it. I thought of it as a leap of faith. My faith was strong. Faith in myself, my family, my friends, my place in the world. I have faith in the future. Faith in my future. I feel free. I. Love. Flying. I will never stop. Do my parents like it? No. Is it the most fun I've had in this little world? Absolutely.

Foundation:
The Habitat as a Living World

Habitat Form

The interior environment of a space habitat can vary widely, affected by numerous design decisions. As the Project Hyperion guideline documentation specifies a planet-like environment, many potential design decisions would be undesirable. For example, a planet-like environment is best simulated by a larger interior volume rather than an agglomeration of many small volumes. Mass efficiency requires that such a large interior environment be as lean as possible, so a ring-configuration would not be as efficient as a drum. For this reason, a large, singular volume was chosen for the form of the habitat of the generation ship. Mass efficiency considerations also suggest that the habitation surface should be concentric with the structural hoop (the structure in tension that keeps the rotating habitat together), so a rotating drum shape was selected as opposed to a bola configuration (for instance) as it is less efficient from a volume and mass standpoint. For space efficiency and ease of access/engineering/structure, the rotating habitat should be completely pressurized, which indicates that the pressure shell of the habitat should be convexly curved; this consideration points to convex endcaps for the rotating drum. The contours of the interior terrain are largely bowled (see *Environment*), so an ellipsoid shape was chosen in order to reduce the amount of terrain fill used under the soil layers, as well as reduce the superfluous structural strain at each end of the habitat. The endcaps are utilized for integrated equipment and spare component storage, utilizing the rarified gravity at higher levels to reduce the strain on the structure. The centers of the endcaps are ideally suited for zero-gravity workshops.

Since the habitat's rotational control is guaranteed in the scope of the ship design (in other words, the habitat is not at risk of a tumbling catastrophe), rotational stability is not a concern and the proportions of the drum should work to both increase comfort and reduce surface area. As for the diameter of the drum, this is a consideration in which we have prioritized the criteria of planet-like environment as opposed to mass optimization for reasons discussed elsewhere (see *Level of Technology*, *Environment*, and *Ecosystem*). For this submission, a radius of 1,000 meters and length of 2,500 meters was chosen, largely sized based on food production and habitat self-sustainability considerations using permaculture farming techniques. These factors provide a rough order of magnitude estimate on habitat mass at 5.17×10^{11} kg, though this number is liable to change significantly depending on the chosen structural material and terrain depth.

Environment

The interior of the habitat is designed to simulate an Earth-like environment (and all that entails) as much as possible on an interstellar generation ship. As such, the interior simulates an "exterior" environment, within which dwellings are constructed. This environment possesses many attributes similar to Earth, however there are also those that cannot be easily replicated.

Gravity

Centripetal acceleration is used to simulate gravity, which is achieved by spinning the habitat. At 1,000m in radius, Earth-like gravity (1G | $9.8m/s^2$) is reached at a rotation rate of 0.0990 rad/s (0.945 RPM) at the furthest point from the axis of rotation. As traversing terrain brings the inhabitants to higher elevations (see *Terrain*), they experience less gravity since their rotational radius is smaller. The minimum gravity level someone could achieve while standing on solid ground is 0.8G | $7.83m/s^2$. While this would be a noticeable reduction in the experience of gravity, it is unlikely to negatively impact the environment or the inhabitants. There would be no permanent dwellings constructed at this high elevation (at the time of construction), so the momentary reduction in gravity is unlikely to adversely affect the anatomy of the inhabitants. Additionally, reduced gravity can have a stabilizing effect on terrain, as it reduces it's own gravity load. On the other hand, gravity should not be reduced too much, as this may adversely affect the reliability of flowing water.

Sunlight

Sunlight provides energy, light, and warmth to most living things in Earth's biosphere. A similar source of light is designed into the habitat which we have named the Sunbeam. The Sunbeam is a large axial beam that spans the length of the habitat, supported by its own stiffness and the rarified gravity at the center of the axis of rotation. High-powered LED light modules span the length of the Sunbeam. At the beginning of each day, the light modules at one end of the beam begin to illuminate, with subsequent modules illuminating along the length of the beam along the course of the day. This travelling light source adds dynamism and increased light access to the habitat. Such dynamism is important for human psychological health (sense of time and dynamism) and reliable light access to ground-covering foliage.

Wind

The movement of air serves more functions than is commonly recognized. These include air mixing, ventilation, seed/pollen spreading, increased rate of photosynthesis, increased psychological wellbeing, and power generation, among others. The simple dynamic movement of air has many benefits indeed, and for people to spend their entire lives inside an environment free of wind seems close to cruel punishment; even most prisoners on Earth are afforded the grace of time outside.

We have designed the habitat environment with wind in mind. As air is a fluid, it can move separately from the ground of the habitat. By introducing terrain obstacles (see *Terrain*) in the rotating path of the habitat, currents of air form, also considered turbulence. This only occurs so long as there is a differential rotational speed between the air air and the ground. Friction and fluid viscosity will eventually force the air into synchronous rotation with the habitat, removing the wind. To avoid this, fast-rotating air must be removed from the perimeter and routed to the slow-rotating axis via the endcap infrastructure (see *Habitat Engineering Systems*). This system can be combined with the forced air required for auxiliary air treatment and for cooling the Sunbeam. By slowing down the fast-rotating air, the presence of wind can be maintained.

Another source of breeze comes naturally as a consequence of differential heating and cooling. As air passes over cool areas (such as streams or shaded terrain), it will fall relative to air that passes over warm areas (such as dark, absorptive surfaces). This creates an additional dynamic source of breeze as the heating over the course of the day changes the direction of this convection, helping to create a changing, dynamic system of moving air.

Terrain

In a rotating habitat designed to replicate a planetary environment, special attention must be given to the shape and composition of the terrain. A well-designed terrain has the capacity to increase surface area, provide gravity-fed drainage, form dynamic breezes, block disorienting views, and generally better-represent a planetary environment. Completely flat terrain (having no change in radius) cannot contribute to any of the aforementioned benefits. When compared to a flat surface, a surface that has varying elevation has a larger exposed surface area. This surface area increase means that there is more area to inhabit and/or grow plants on. Considering the constrained size of the habitat, any increase in surface area without increasing the overall size of the habitat is an advantage. We propose a varied landscape fabric with rolling hills, ponds, and small cliffs. Broadly speaking, the circumference of the habitat will be divided into three areas defined by valley regions, each separated by ridge regions. While these regions are identifiable by their terrain, the regions are connected to one-another via passages through the terrain in one manner or another.

Ordinary rain is not possible in a rotating habitat of the size considered for this design, and may not even be feasible on habitats smaller than hundreds of kilometers in radius. As such, water needs to be transported around the habitat for irrigation and other purposes such as energy collection. Since the area of the habitat is substantial, transporting water throughout the habitat using piping systems is unfeasible as this requires considerable hidden infra-structure that will undoubtedly require intensive ongoing maintenance. Instead, we suggest only a smaller number of central water pumps and conduits (see *Habitat Engineering Systems*) that transport water from the low-laying, water-collecting regions to the highest ridges where the water can fl ow back down to the low-lying regions via streams or aqueducts.

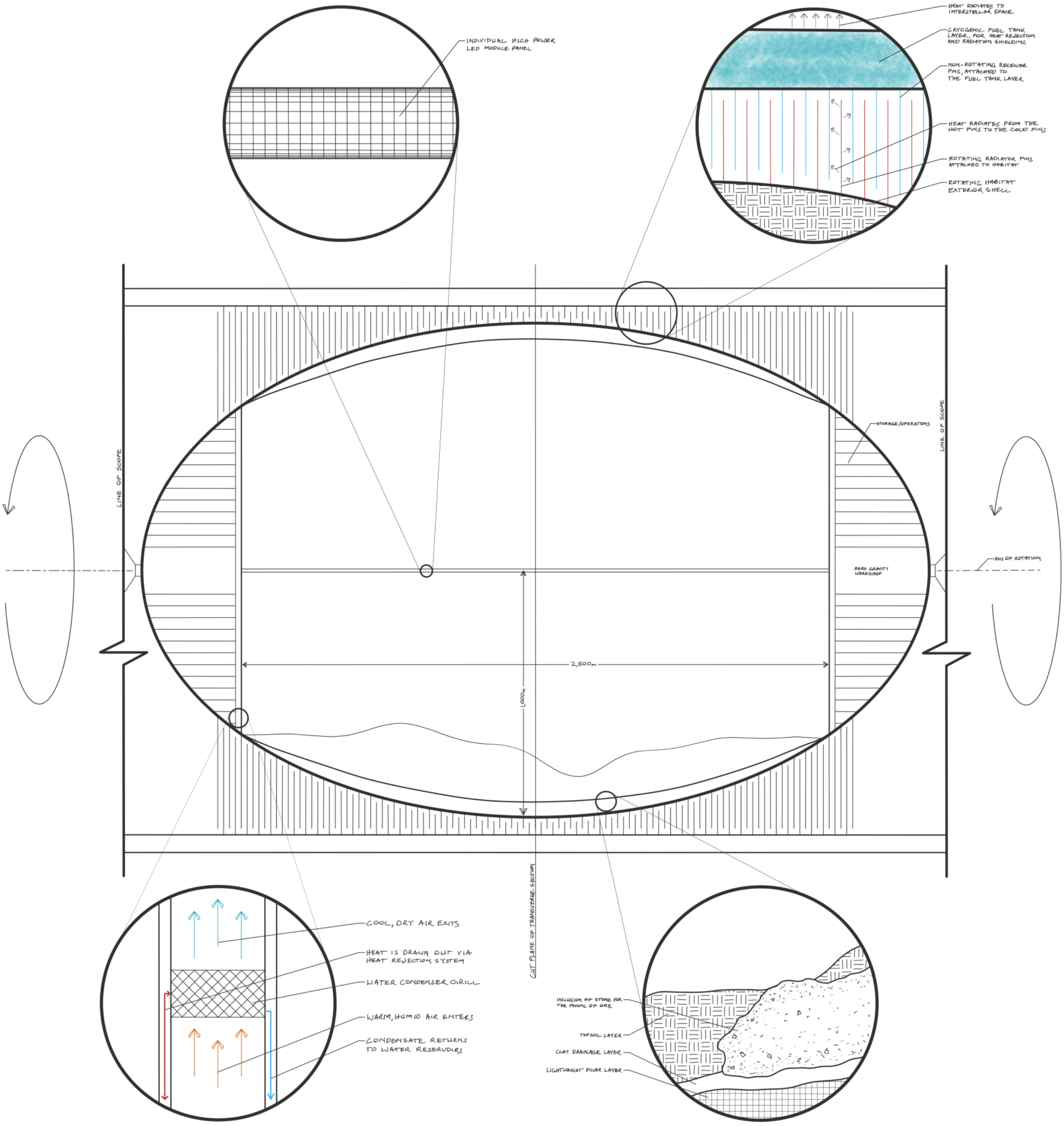
By shaping the terrain into these circumferential valley-ridge regions, air that has a differential velocity to the surface of the habitat is drawn into the valleys over the ridges and then back up over the ridges on the other side of the valleys (see *Wind*). Specific regions can be shaped to increase this air velocity while other regions can be shaped to minimize it. An acutely concave landscape is surely alien to Earthlings and if left unchecked, cause disorientation among the inhabitants. To help combat this, the valley-limiting ridge regions help block the sightlines of the nearby valley regions along the circumference of the habitat.

Ecosystem

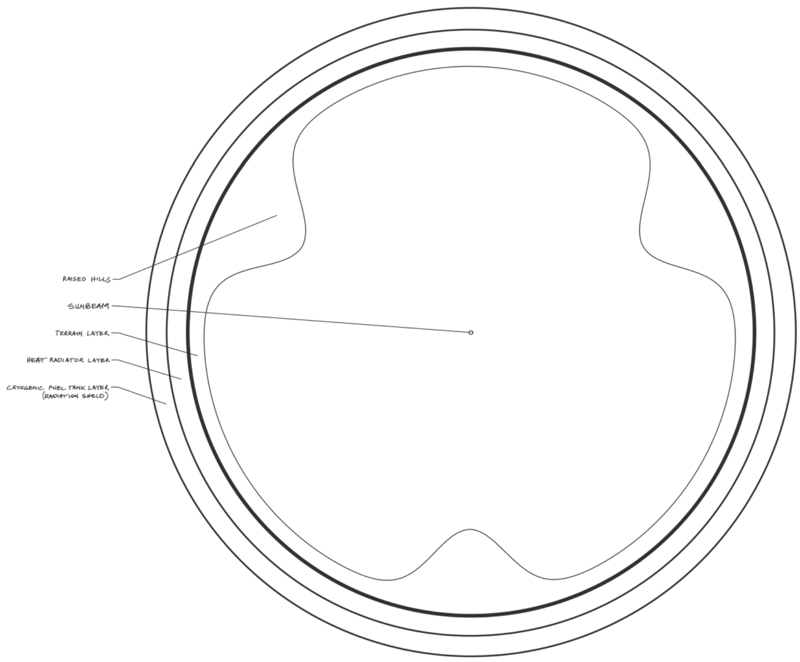
The ecosystem within the habitat is designed to be a dynamic, evolving system able to sustain itself over the course of the 250-year journey. Rather than a static, artificial environment requiring constant human intervention, the goal is to cultivate a resilient biocylinder of sufficient size where natural processes regulate balance, ensuring stability and adaptability. The total area required for a fully contained and self-sustaining ecosystem has been estimated to be upwards of 1,200 hectares. Our design provides this area with an additional margin on top. A 1,000 meter radius by 2,500 meter length provides a surface area of 1,500 hectares. A habitat of this size should easily be able to provide a stable and regenerative ecosystem while feeding a human population of at least 1,500 individuals.

At the foundation of this ecosystem is the microbiome—an intricate network of bacteria, fungi, and other microorganisms that underpin soil health and nutrient cycling. The soil itself will be a composite of Earth-derived organic matter, augmented by a carefully managed cycle of decomposition and renewal. These microbial communities play a crucial role in maintaining fertility, breaking down organic waste, supporting plant growth, and providing improved nutrition. Having a healthy and diverse microbiome also contributes to improved human health and resiliency; after all, humans contain more bacterial cells than "human" cells.

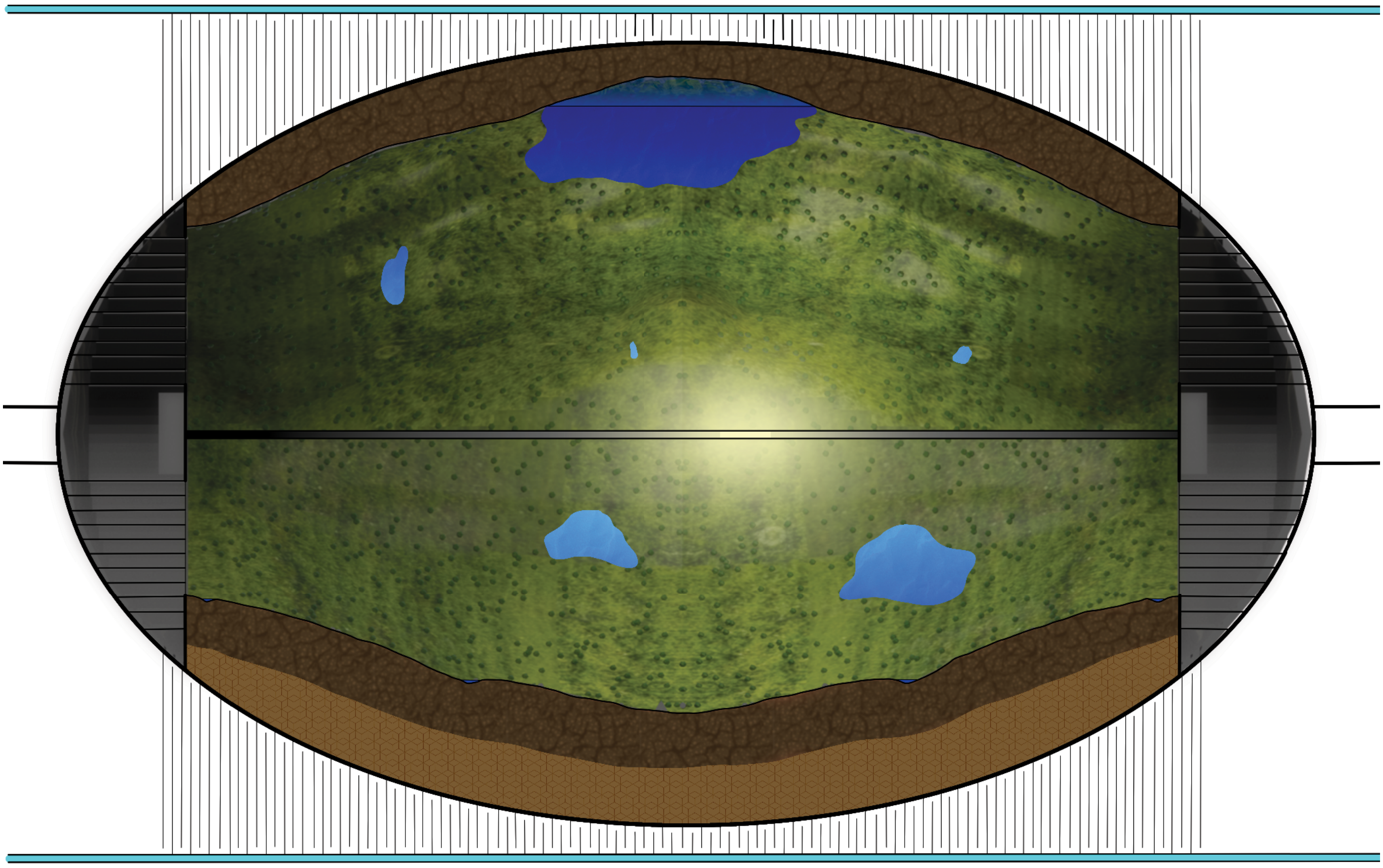
Flora	Fauna	Microorganisms
Oak Trees, Bamboo, Fruit-bearing Trees (Apple, Fig, Citrus), Leguminous Plants (Soy, Peas, Clover), Wetland Plants (Reeds, Water Lilies), Grasses and Ground Cover (Alfalfa, Ryegrass)	Pollinators (Bees, Butterflies, Moths), Detritivores (Earthworms, Dung Beetles), Small Mammals (Rabbits, Squirrels), Amphibians (Frogs, Salamanders), Reptiles (Turtles, Small Lizards), Fish (Rainbow Trout, Tilapia), Birds (Songbirds, Raptors for pest control), Larger Mammals (Goats, Pigs for ecosystem management)	Nitrogen-Fixing Bacteria (Rhizobia, Azospirillum), Decomposers (Fungi, Actinomycetes), Water Purifying Bacteria (Denitrifiers), Mycorrhizal Fungi (Enhancing plant nutrient uptake), Lactic Acid Bacteria (Fermentation and gut health), Methanotrophic Bacteria (Reducing methane emissions)

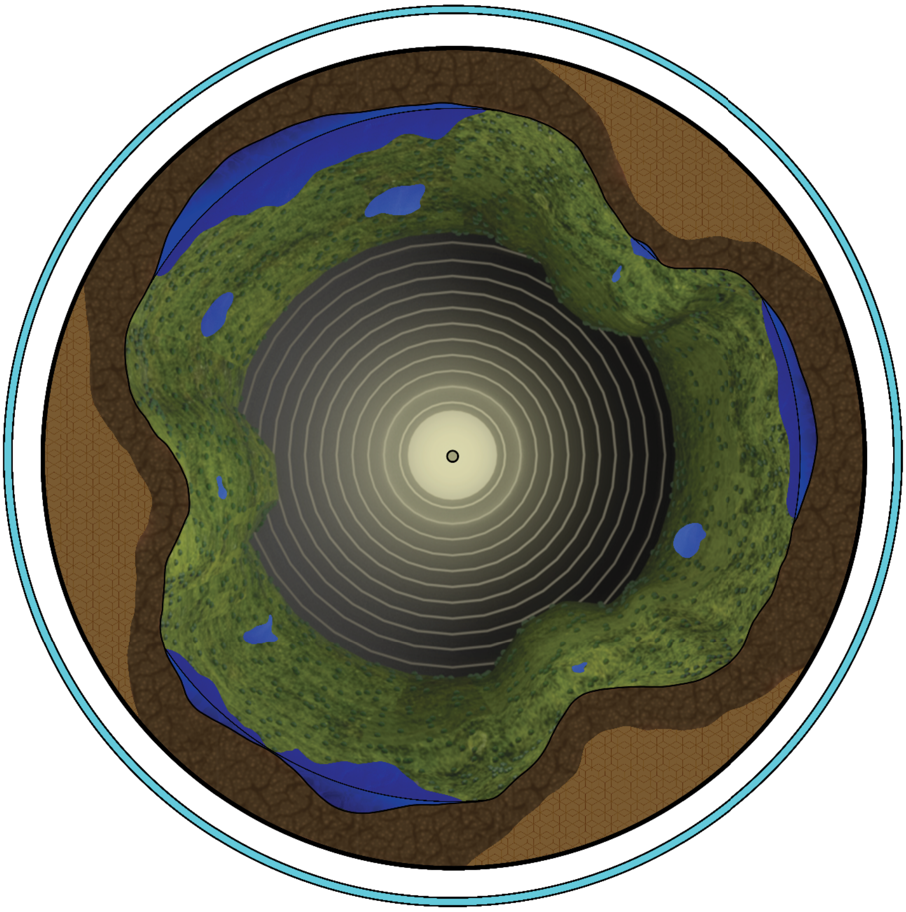


INDIVIDUAL HIGH POWER LED MODULE PANEL
HEAT RADIATES TO INTERSTELLAR SPACE
CRYOGENIC FUEL TANK LAYER, FOR HEAT REJECTION AND RADIATION SHIELDING
NON-ROTATING RECEIVER FINS, ATTACHED TO THE FUEL TANK LAYER
HEAT RADIATES FROM THE HOT FINS TO THE COLD FINS
ROTATING RADIATOR FINS ATTACHED TO HABITAT
ROTATING HABITAT EXTERIOR SHELL
LINE OF SCOPE
STORAGE/OPERATIONS
LINE OF SCOPE
ZERO GRAVITY WORKSHOP
AXIS OF ROTATION
2,500m
1,000m
CUT PLANE OF TRANSVERSE SECTION
COOL, DRY AIR EXITS
HEAT IS DRAWN OUT VIA HEAT REJECTION SYSTEM
WATER CONDENSER GRILL
WARM, HUMID AIR ENTERS
CONDENSATE RETURNS TO WATER RESERVOIRS
INCLUSION OF STONE FOR THE MINING OF ORE
TOPSOIL LAYER
CLAY DRAINAGE LAYER
LIGHTWEIGHT FILLER LAYER



RAISED HILLS
SUNBEAM
TERRAIN LAYER
HEAT RADIATOR LAYER
CRYOGENIC FUEL TANK LAYER (RADIATION SHIELD)





Flora and fauna are selected not only for their immediate roles in food production but also for their contributions to ecological complexity. The landscape will include a diverse array of plant life, ranging from staple crops and fruit-bearing trees to dense undergrowth and fast-growing nitrogen-fixers. Cultivation of bamboo networks will contribute to various microclimate opportunities and will provide fast-replenishing building material for the con-structed environment. A mixture of grasses, bushes, and tall canopy trees will create a multilayered environment, mimicking the structure of natural ecosystems to maximize biodiversity and resilience. Macro-fungi species will aid in decomposition and nutrient cycling, while pollinators such as bees and butterflies will be essential for plant reproduction. The fauna within the habitat will be similarly diverse, with a mix of small mammals, birds, reptiles, fish, and invertebrates. Aquatic environments, including lakes, rivers, and wetlands, will support fish and amphibian populations. The selection of species must be well-considered to maintain ecological balance and to prevent overpopulation of any single species.

The proportion of ecosystem area used for the production of food intended for harvesting for human consumption will be a minority (about 20%) of the total ecosystem area. This is more than enough to provide sustenance with plenty of room for flexibility if circumstances change at a later time.

Integration with human habitation is a key principle of this design. The constructed environment will not exist as isolated, separate constructs but will be interwoven with the environment, incorporating water and plant life. The presence of natural corridors will allow wildlife movement and contribute to ecosystem connectivity, reducing the need for artificial interventions.

Overabundance, rather than scarcity, will be a guiding philosophy in ecosystem design. By fostering an environment with more biodiversity than immediately necessary, the system will have the capacity to adapt and evolve. This built-in redundancy ensures that unforeseen challenges—such as shifts in species populations or climate variations—can be absorbed without threatening the stability of the entire biocylinder. This overabundance also bolsters the capacity to carry this diversity to the surface of the destination planet upon arrival.

Ultimately, the ecosystem is not merely a background feature of the habitat but its living, breathing foundation. As such a complex system as it is, it will likely require some years of growth prior to launch to fully mature to its designed state of stability. It will function as both a provider and a regulator, supplying food, air, and water while maintaining the necessary cycles of renewal and adaptation that will sustain life across generations. We do not demand efficiency of the ecosystems of Earth. On the contrary, we encourage Earth's biosphere to be plentiful and highly diverse, and it is these qualities we celebrate in Earth's ecosystems. We believe the biocylinder should be just as abundant and diverse, if not more.

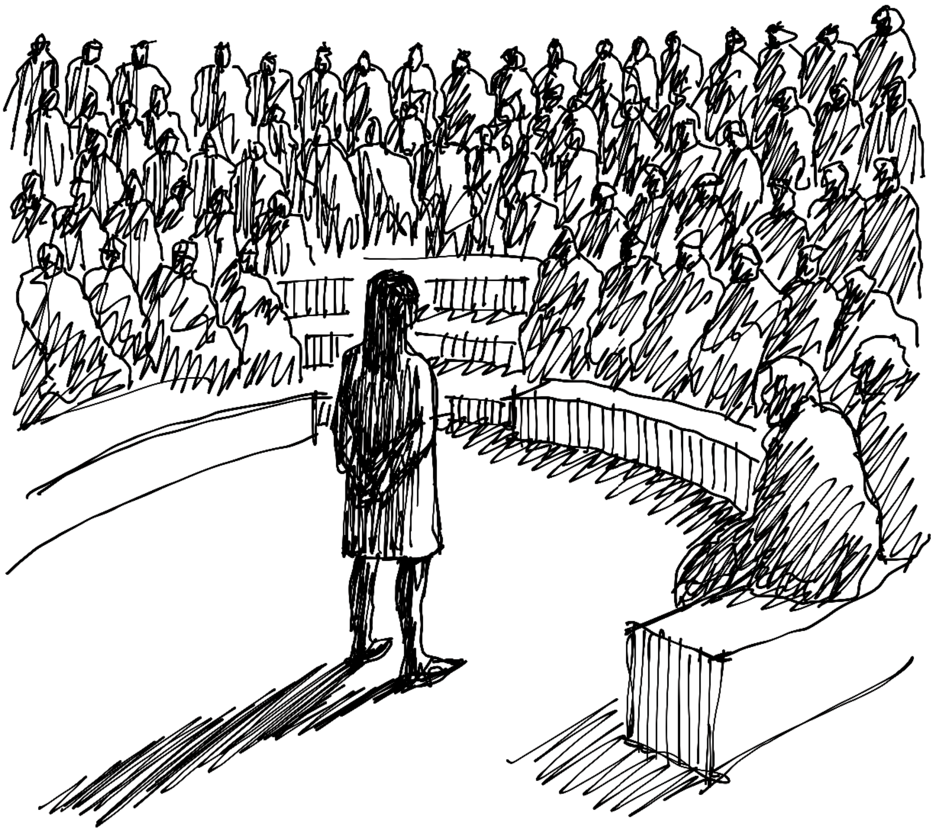
Inhabited Architecture

In the context of the Neo-Genesis Seed, dwelling architecture should emerge not as a top-down prescription, but as a living extension of the biocylinder—responsive, adaptive, and inherently local. Unlike the engineered habitat superstructure, these inhabited spaces belong to the cultural and ecological substrate of the settlement, forming what might be termed a new vernacular architecture.

Freed from terrestrial constraints such as rainfall, these dwellings are instead designed around light, temperature, and moisture regulation. Passive thermal strategies, shading systems, and breathable materials take precedence over impermeability. They are also shaped by the need for separation from wildlife—microbial or otherwise—while preserving permeability to the ecosystem where appropriate.

Constructed from available and renewable materials such as timber, bamboo, fiber composites, glass, metal fasteners, and gravel-like aggregates, these structures reflect a low-tech, high-skill philosophy. As communities grow and diversify, these buildings will evolve in function and form, shifting with social dynamics, family structures, and aesthetic sensibilities.

The bamboo dwellings of Indonesia provide a precedent: lightweight, resilient, and tied to tradition, they demonstrate how architecture can arise from material ecology and cultural continuity. Neo-Genesis Seed invites a similar approach: architecture as an expression of stewardship, shaped over time by its inhabitants.



I took a deep breath before stepping out to the center of the amphitheater. I did not want to be called twice. It was already getting dark, the shadows long. The important issues were already discussed, though I could not focus on them. As much as I was nervous in the presence of the council, it was everyone looking at me that made me the most self-conscious. My mother's father was here, even though he hadn't come to council since I was too young to attend. He had always complained that it was too far, too long-winded, and altogether not worthwhile, however he was here today. Perhaps he wanted to be supportive, but all I felt was shame. Someone began to speak.

"Having heard prior testimony bearing witness against the accused, this council holds Djan Seriy Anaplian to account for the misappropriation of preserved foodstuffs intended for the upcoming harvest festival. Please make your case as you know it."

With a hesitant voice that I quickly forced into action, I told them the circumstances of my youthful transgression, though I made no mention of the other beneficiaries, naturally. Some of the elders asked stern questions, which I answered with deference and remorse. The quicker I could do this, the quicker someone else would get the public's attention. They left the vote to the attendees. A warning this time...

Society & Culture:
The People Who Live Here

Governance

Ultimately, the ecosystem is not merely a background feature of the habitat but its living, breathing foundation. As such a complex system as it is, it will likely require some years of growth prior to launch to fully mature to its designed state of stability. It will function as both a provider and a regulator, supplying food, air, and water while maintaining the necessary cycles of renewal and adaptation that will sustain life across generations. We do not demand efficiency of the ecosystems of Earth. On the contrary, we encourage Earth's biosphere to be plentiful and highly diverse, and it is these qualities we celebrate in Earth's ecosystems. We believe the biocylinder should be just as abundant and diverse, if not more.

Values

Values are the guiding light that facilitates the constructive assessment of performance for all things. In the case of a small society onboard a generation ship, there are a few foundational values that can help to inform how such a society is structured and governed, and these values each stem from one or more of the following axioms: *morality* and *mission success*.

The first value is *Ensure Quality of Life*, and it is a primary derivation of the axiom of morality. If we are to spread humanity beyond our home solar system, it is important that we do not increase the amount of suffering. This reasoning is born out in the field of population ethics and is foundationally important if we are to design this mission to be successful, both because ensuring quality of life is conducive to mission success and because success implies a greater number of humans who have the capacity to experience suffering. Additionally, a higher quality of life is positively correlated with other important capabilities such as knowledge retention. When designed with the foundational value of ensuing quality of life, a society is set up to have social prosperity designed into it rather than it being hoped for as a side-effect.

The next value derived from morality is *Protect Individual Liberties*. Each individual should be secure in their person and should not be coerced into actions that would violate their the ownership they have over their body.

Next is the value a *Healthy Population Curve*, which is a primary derivation of the axiom of mission success. There are two ways in which the population dynamics can jeopardize the mission: a population surge and a runaway population decline (see *Population Dynamics*). While a population surge is challenging, the solution is relatively easily modeled and accommodated using simple (if extreme) reproduction policy controls. A runaway population de-cline on the other hand is much more difficult to recover from without transgressing against the aforementioned morality values. Consistent tracking, transparent communication, and a collectivist social attitude can help to ensure that the population stays on track over the centuries-long journey.

Last is the value of *Knowledge Continuity*, which is very strongly linked to mission success. Without retaining both tacit and codified knowledge, the mission has no hope of meaningful success (see *Knowledge Continuity*). Without hope for success, there is no purpose in the mission itself. This consideration takes precedent over all others, even mass budget; what point is there to be stingy with mass if the mission is destined to fail as a result?

Goals

Secure and Just Community

Security and justice are essential for a sense of public confidence in good outcomes in the future. The job of maintaining such a lifeboat across the void of interstellar space is solemn enough without being concerned about whether one's self or loved ones will return home without being accosted or detained on false accusations. In many ways, this is the challenge of all governing bodies: balancing the formation, enforcement, and adjudication of law with each other in a dynamic public arena where attitudes and tolerances may change over the years, let alone the generations. What is important is that whatever solution is used, the public should have a favorable view of the safety of their community and fairness in its management.

If individuals do not feel the community is secure or just, this would certainly go against the values mentioned above, especially those of *Ensure Quality of Life* and *Protect Individual Liberties*, as an unsafe and unfair community is bound to reduce the quality of life and liberties of the public. By extension, this reduction in quality of life and liberty is bound to have a detrimental effect on the values associated with mission success as well; if the public does not believe in an optimistic future, they would be less-likely to want to have children (*Healthy Population Curve*) or care about retaining knowledge (*Knowledge Continuity*). As the consequences of failing to embody a secure and just community strike at the heart of each of the proposed foundational community values, establishing a secure and just community should be a non-negotiable goal of any governing body aboard a generation ship.

Public Trust

Public trust underpins a society's stability and long-term health, especially in a confined, interdependent environment like a generation ship. When people trust one another and their leadership, they cooperate more readily, adhere to community guidelines, and remain engaged in governance. This trust fuels optimism about the future, encouraging actions that protect individual liberties, preserve knowledge, and ensure a healthy population curve. Conversely, when trust erodes, the negative impacts are swift and far-reaching. Moral codes falter, as individuals may doubt the fairness of the system and become cynical or disengaged. Suspicion spreads, stoking tension and undermining collective problem-solving. Over time, this damages the operational effectiveness of the multi-generational mission, jeopardizing the very values that the governing body was meant to uphold. A public who trusts their governing bodies is better-positioned to achieve mission success and remain a bastion of morality, therefore public trust should be considered a foundational goal.

*Adaptable to Changing Circumstance*s

Adaptability is central to both morality and mission success. In the case of a small society onboard a generation ship, where conditions can shift over time due to changing technology, resource availability, or social dynamics, it is necessary that the community be pre-pared to evolve its customs and practices without compromising its foundational values. By cultivating a culture of openness, one that actively incorporates novel methods, data, and perspectives, the society ensures it does not stagnate. With leadership and community members continually revisiting assumptions and welcoming constructive critique, the mission remains flexible yet steadfast in its overarching goals. In this way, the capacity to adapt bolsters mission success across generations, aligning stable governance with the practical realities of an ever-evolving journey.

The risk in a community government that is too rigid is ever-present, yet unpredictable. A governing system and policy that works at year 1 may not work as well at year 50, let alone year 200. Outdated policies and mechanisms can yield dissatisfaction and fragmentation, each a real threat to security and the societal sense of justice.

Social Risks

Knowledge Loss

It is difficult to understate the degree to which the success of the mission and indeed the lives of the entire crew depend on the robust continuity of knowledge. This includes not only codifiable knowledge, but possibly even more importantly tacit knowledge (see *Knowledge Continuity*). As critical as it is, it is potentially just as precarious, and a community government that is blasé about knowledge retention is setting the mission up for failure. Thusly, the government should be proactive in its accounting of knowledge/proficiencies, and should be able to set policies and incentives as it sees fit to ensure that critical knowledge (if endangered) is not lost.

Power Consolidation

This risk may be the one with the most gravity for the quality of life of the inhabitants of the generation ship. In all societies, the potential exists for power and influence to go from being distributed to being concentrated in fewer and fewer individuals. This is as true in the world we live in as it could be on a generation ship, however the risk is much more potent in small communities. In a society of 1000 individuals aboard a generation ship, the risk of power consolidation is great indeed, and measures to reduce the chances/trends of power consolidation must be taken to uphold the foundational values of the mission. Whether fast (as in an uprising of the malcontent) or slow (as in the gradual appointment of partisan autocrats), power consolidation would likely (at least for a portion of the population) lower quality of life and reduce individual liberties, consequently impairing knowledge continuity and shocking the population curve.

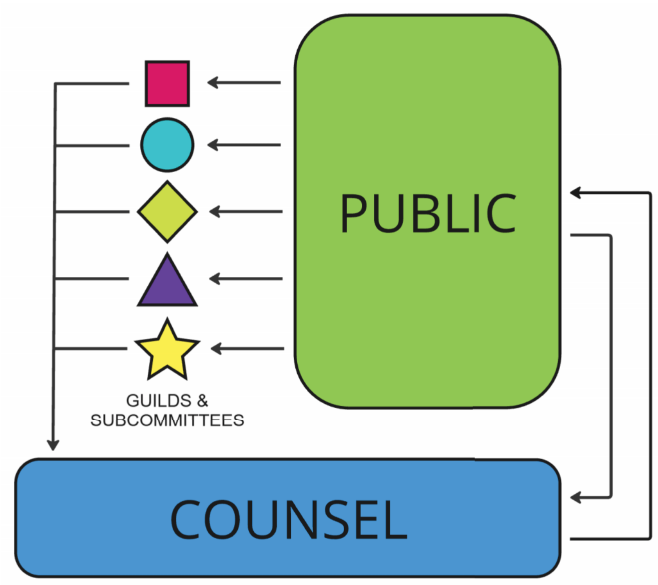
Unhealthy Population Curve

Through myriad factors that are only partly under the control of society, whether govern-mental or individual, a healthy population curve is crucial for the future of the mission. On the one hand a population surge may strain resources and cause future recurring issues in the population curve, while on the other hand a runaway population decline has catastrophic implications for the future of the society (possibly including failure). If the population raises to approach the carrying capacity of the habitat, policies (such as a child limit) may have to be enacted, which would begin to violate individual liberties though there is a historical precedent for such policies. If the population is reduced sufficiently from the ideal curve (see *Population Dynamics*), follow-on effects such as knowledge loss and maintenance-related equipment failures begin to occur, and beyond some threshold the population is unable to recover without severe intervention. Such extreme interventions (eg: compulsory motherhood) are entirely in violation of individual liberties and should be avoided by designing more proactive interventions that work at the social level when potential issues can be resolved without resorting to the violation of human rights.

Prescription

A governing system that resonates with the axioms of morality and mission success should balance the dynamic needs of the community while ensuring that no single faction consolidates undue power. One such structure would be a council composed of representatives from the various subcommittees (each responsible for analyzing critical societal trends and metrics in critical areas such as population dynamics, resource allocation, and knowledge retention) and from the various professional guilds crucial to the mission's viability (for example: metalworking, life-support, medicine, agriculture, maintenance, etc.). This arrangement upholds the foundational values by allowing each area of expertise to have a clear and consistent voice in matters of policy.

Although the council itself provides continuity, the position of council chair is designed to be a rotating appointment, filled at regular intervals through election or temporary council consensus. This rotation of leadership safeguard against the stagnation that can lead to one form of *Power Consolidation*, while maintaining a practical framework for guiding the mission over centuries. By rotating the chair, the community gains fresh perspectives in leadership, without disturbing the broader com-position of subcommittee and guild representatives whose ongoing work and oversight are key to day-to-day stability.



During council deliberations, which take place in transparent public sessions, members bring forth insights from their respective subcommittees or guilds and collaborate on solutions aligned with the goal of being *Adaptable to Changing Circumstances*. In parallel, specialized data, ranging from population metrics to resource management projections, flows consistently from the subcommittees, enabling informed decision-making. Any significant measures that may affect large segments of the population are then subject to public input through referenda or open debate, allowing for a community-driven approach. This also ensures that public participation remains a vital component of governance, fostering both trust and adaptability.

Checks and balances between the council, subcommittees, guilds, and the public further reinforce the goals of a *Secure and Just Community* and robust *Public Trust*. Proposed legislation, and perhaps even constitutional changes, can be submitted, contested, refined by subcommittees, or subjected to public referendum to prevent unilateral action. In this way, authority is neither centralized nor inert, but fluid, guided by evolving needs and the principled stewardship of diverse representatives, all working under the unifying vision of a morally sound and mission-focused society.

Population Dynamics

Reproduction is a quality that has been selected for in all extent forms of life, as every lifeform alive now would not be here if their predecessor had not reproduced. When it comes to humans, inclination towards reproduction varies widely and outcomes are difficult (neigh impossible) to predict at small scales, let alone through multiple generations into the future. For contemporary humans, reproduction is an extremely personal choice (albeit influenced by family and culture). Removing this choice from individuals, one that is so inexorably connected to the essential right of bodily autonomy, would work against the foundational values of such an intrepid society (see *Governance*). It is therefore in the best interest of said society to maintain that ultimate reproductive rights remain with the people. That being said, inclination to reproduce may indeed be influenced by policymaking.

Population Control Policies

In nature on Earth, species in population equilibrium trend toward stable numbers over the short-to-medium term. This is due in large part to the stabilizing effects of territory and food supply; for example, if a population expands too rapidly, their increased numbers will likely diminish the food supply such that the population is reduced through starvation-related effects. Humans have circumvented the immediate negative effects of expansion over time through advanced trade and the use of agriculture with increasing efficiency over time. This circumvention has propped-up humans relatively well, however in a closed system with limited technology we are still prone to the population-stabilizing effects of resource depletion (see *Governance*). Thus, it is of great importance that the total population be kept under a maximum critical threshold defined by the carrying capacity of the habitat. This carrying capacity may be substantially larger than the designed population size, but must also be balanced with resources needed for long term ecosystem health (see *Ecosystem*). At the same time, due to the minimum population required retain critical knowledge (see *Knowledge Retention*), maintain technology supply chains (see *Level of Technology*), and ensure adequate genetic diversity, it is also critical that the the total population be kept above a minimum critical threshold.

Discussing the subject of population control tends to make people feel uncomfortable. Indeed, being told by a governing authority that one cannot procreate (or more problematically: that one must procreate) seems a violation of basic human freedoms, let alone basic biology. Another issue stems from a seeming lack of reasonable enforcement capability, especially in an environment with limited medical technology (see *Level of Technology*). What is the consequence if someone spurns a prohibition on procreation when abortion technology is not available? Certainly child murder is out of the question. What is the consequence of abstaining from procreating when procreation is an edict? Certainly forced impregnation is out of the question. A more careful consideration of policy in the realm of population dynamics may shed some light on the constraints of this exercise. There are indeed policies that can have a beneficial effect on controlled reproduction without over-stepping ethical boundaries. Some examples of these include parental incentives, partner matching events, enhanced education programs, family planning, contraception education, and community support initiatives. Most importantly, it is vital that the population heath be assessed regularly and the recommendations be communicated to the public transparently so that social pressures can do the work of moderating the birthrate (see *Population Simulations*).

Population Curve

Determining the ideal population curve requires considering whether the population should remain constant over 250 years or vary over time. This assessment is critical for evaluating the effectiveness of different approaches to population size over time. From the perspectives of genetic diversity, knowledge retention, and technology level, maintaining a minimum population is vital. In these areas, larger populations offer increased redundancy and greater potential for specialization in knowledge and technology. Consequently, it is advisable that the population not significantly decrease below its initial size. If the population should not decrease, should it remain static or grow? While a constant population can sustain knowledge and technology levels, it may not foster the growth momentum necessary upon reaching the destination planet. Expansion of technological capabilities planet-side hinges on the growth of the settlement's population. Cultivating a culture of steady population growth during the voyage can facilitate faster and healthier expansion after arrival. Hence, an incremental population increase from an initial 1,000 individuals to around 1,500 individuals is proposed as a benchmark. This number represents a target rather than an absolute limit; however, maintaining a balanced and healthy population pyramid is ultimately more critical than adhering strictly to peak population figures.

Population Pyramid

Assessing population health effectively involves more than just examining total numbers or growth trends; a comprehensive evaluation includes reviewing the population pyramid. This graphical tool depicts age and gender demographics, providing insights into the structure of the population. A healthy pyramid typically appears symmetrical and bottom-heavy, indicating a stable foundation of younger individuals. An unhealthy pyramid, on the other hand, might exhibit asymmetry or a smaller cohort of young people compared to the middle-aged or older populations.

Although population pyramids are particularly useful for evaluating established populations, they can also highlight significant issues in newly constructed populations. Initially, constructed populations often deviate from natural demographic distributions, as selections prioritize experienced, knowledgeable, and trained individuals crucial for establishing habitat and culture. Such populations likely contain a higher proportion of middle-aged adults, fewer children and young adults, and fewer established families.

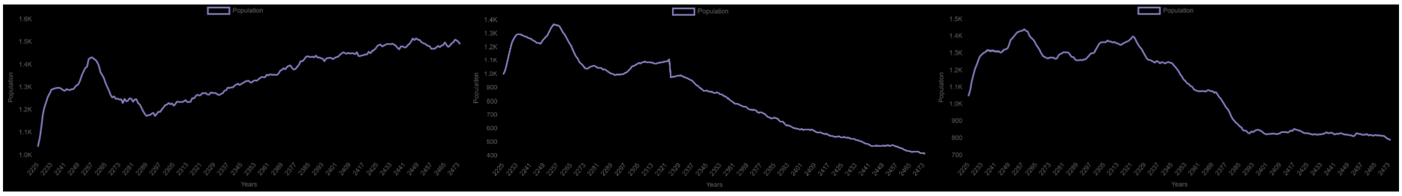
Initially, this produces a middle-heavy pyramid, which tends to trigger rapid population growth as relationships form, and new generations are born. However, this growth inevitably slows, and a subsequent decline occurs because the initial younger generation is proportionally small, causing birth rates to fall when these individuals reach childbearing age. It typically requires several decades for the population pyramid to stabilize, achieving a more sustainable, bottom-heavy structure and steady population growth.

Population Simulations

In an effort to determine what such an isolated population might experience with respect to reproduction demographics and population, we created an agent-based population simulation tool, featuring numerous tunable factors related to biology, relationship dynamics, and demographics in an aim to predict how changes in the variables can affect the population curve over the centuries in an effort to prove feasibility and adherence to the mission design parameters.

The only tool used in the simulations to moderate the birthrate was a variable factor representing the social attitude toward having additional children, adjusted according to demographic assessments (see *Population Control Policies*). When the assessment indicates that more children should be born, the factor is greater than 1; when fewer children are recommended, the factor is less than 1 (but never 0). This factor is used in the simulation when determining whether an individual becomes pregnant and is used in tandem with a variety of other probability factors related to biology, individual preferences, and relationship dynamics. The factor moderates the likelihood of pregnancy rather than determining whether someone can or cannot become pregnant. In practice, pregnancies are still allowed during periods where fewer children are recommended, however they are less likely due to this social pressure.

Additionally, we simulated several events which would pose challenges to the population curve stability in order to predict which events are the most problematic and should be avoided.



Steady population increase   Decline due to mass child death   Decline due to no child pact

The results of the simulations confirm the phenomenon of population establishment volatility, and also confirm that it is possible to organically increase the population over the course of 250 years without exceeding the upper limit and without enacting fascist population control policies. This is made even more feasible if the mission design is modified such that the habitat is constructed and populated well in advance of mission launch so the volatility in population (as well as ecosystem) can be monitored and augmented as needed.

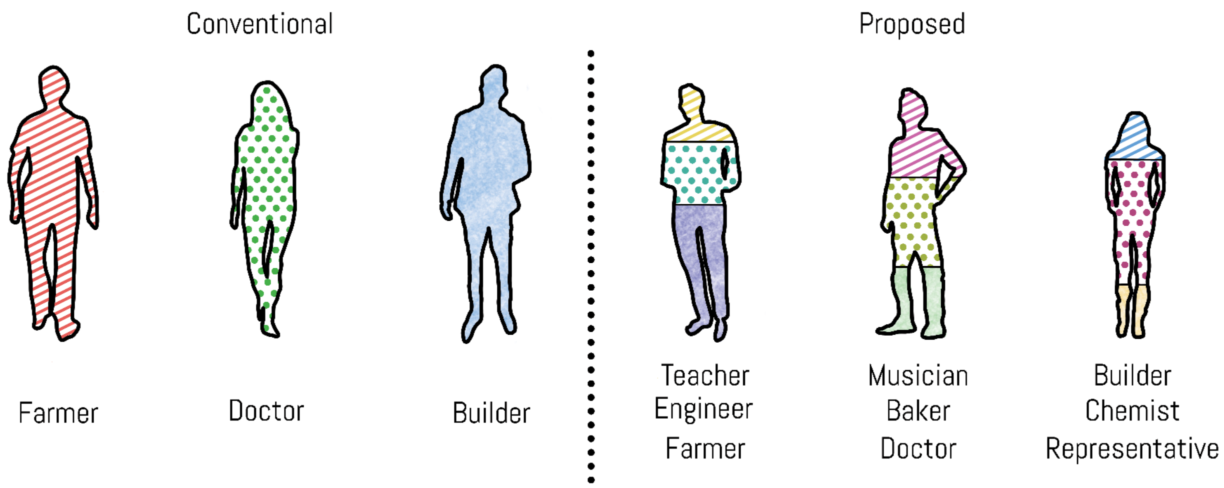
Societal Roles

Life onboard a generation ship is not as simple as merely keeping people alive. The success of the mission depends on everyone contributing to the maintenance, resilience, and prosperity of the community. The way in which individuals participate in the community will vary widely and may be quite different from what contemporary societies on Earth have come to be familiar with.

Occupations

While there are those who work more or less than average, in the contemporary world a prototypical employee works a 40-hour work week. While deeply ingrained in the western world, the 40 hour work week is less than a century old and has its origins in organized labor unions. Prior to this change, it was common for people to work at least 60 hours a week. In contrast, many countries have a workweek less than 40 hours including France, The Nether-lands, Denmark, Norway, and Iceland. It is clear then that there is no magic number weekly employment. Furthermore, the very nature of work and of the commitment necessary for maintenance of skills must be called into question.

It is not clear how many weekly working hours are necessary to maintain proficiency in a given field, however it is very likely that the answer is much less than 40. If this is so, it opens the landscape of occupational distribution beyond that which has been specified before. For example, typically, the total number of employees would be equal to the total number of employed individuals, as each individual has a single occupation, however if each individual splits their time between two or more occupations, the number of "employees" can exceed the number of individuals. Instead of having 2 doctors, a small population can have 10 doctors because each doctor is also engaged with other occupations. This dramatically changes the possible occupational distribution due to the considerations regarding knowledge retention and specialization (see *Knowledge Retention*). If a population of 1,000 individuals can have more practitioners of a certain occupation, knowledge of said occupation is more likely to survive and even improve. Additionally, individuals can have more-specialized occupations, as the multiple occupation



paradigm allows the society to proceed as though it had a larger population than it does as specialization is typically limited by population size (see *Level of Technology*).

In such a society that this submission proposes, occupations play much more of a social role than an economic one, especially in a closed environment. That is, less focus is spent on what resources are gained while more focus is on how important one is to the community and to the mission. This shift in focus away from material compensation and toward social contribution has substantive benefits that must be recognized, such as greater intrinsic motivation among individuals, as their work is valued not merely in terms of personal gain but in how it serves the collective. This fosters a culture of cooperation rather than competition, where expertise and labor are allocated based on aptitude and need rather than market forces. Additionally, such a system reinforces social cohesion, as individuals fi nd meaning and identity in their contributions, reducing the likelihood of alienation or disengagement. Furthermore, by decoupling labor from strict economic motivations or necessity, the society can afford to prioritize occupations that enhance long-term well-being, such as education, therapy, and entertainment, ensuring a richer and more resilient community.

Administration

Beyond the occupational layer, there is also the administrative layer. Societies require structure, and effective organization depends on leaders and public servants. As the governance of the ship is designed to be community-driven (see *Governance*), active participation by the public at large is valuable and necessary. Participation in governing administration can vary widely in responsibility and may include surveying, recordkeeping, organizing, policy-making, judicial, and procedural positions. While some of these positions may be those that can be secondary or even tertiary roles (after their main occupation(s)), there will likely also be those that may become primary roles, at least for a period of time. While important, we feel that administrative roles should be considered as a public service rather than a career path.

Knowledge Retention

Knowledge can be split into two classes based on how it is stored, learned, and interpreted: codifiable knowledge and tacit knowledge. Codifiable knowledge is that which can be both recorded to an external storage media and in some way read from said storage media without loss of fidelity. Some examples of codifiable knowledge include mathematical equations, engineering schematics, explanations of scientific principles, historic facts, etc. By contrast, tacit knowledge is that which is difficult or impossible to record to and/or read from an external storage media with reliable fidelity; rather, tacit knowledge is most often transmitted through experience and mentorship. Some examples if tacit knowledge include manual labor techniques, construction techniques, diagnosis intuition, athletic skill, manual dexterity, and aesthetic assessment. Both classes of knowledge are necessary for a functioning society.

Tacit Knowledge

While the codification of tacit knowledge may be attempted through metaphor and description, such attempts are not adequate for high fidelity knowledge transfer. Because of this, tacit knowledge must live in the minds of those who possess it, and can only be transmitted through mentorship and bolstered through practice. Because of this, tacit knowledge must at all times exist in living memory to ensure continuity. This however is not a simple undertaking. The main challenges to the continuity of tacit knowledge through generations are sudden knowledge loss (ex: through death) and a dearth of transmission/practice. Sudden knowledge loss is at its worst when the knowledge is in the possession of very few individuals and is combated by training more individuals than would otherwise be required of full-time work. An implementation of this practice could be the cultural institution of individuals having more than one profession or specialty. Simply increasing the number of professions an individual has from one to two potentially doubles the protection against critical knowledge loss and increases the number of unique specialties that can be known by a society of a certain size (see *Occupations*).

Healthy transmission and practice are also critical for retaining tacit knowledge. A risk of a dearth in transmission/practice is keenly present in circumstances where the knowledge in question is not contemporaneously required for the functioning of society. For example, if a society uses advanced means to grow produce while attempting to retain tacit knowledge of traditional farming techniques, it is at a high risk of losing the traditional tacit knowledge. The reasons for this come from both the economic and the sociological spheres. Economically, since the advanced method for growing produce is likely more labor-efficient, individuals tasked with growing produce are less-likely to be inclined to spend time and effort maintaining knowledge that will only be needed in a tangible sense only after they themselves are long dead. Sociologically, the values of successive generations tend to drift from those of their predecessors, and this drift includes their attitudes about what heirloom knowledge is important. For instance, research has shown that the importance of heirlooms, for example, tends to diminish after only two generations. To combat these tendencies, it is essential to ensure that critical tacit knowledge is at all times essential. For example, if traditional farming techniques are essential, the society should rely on traditional farming techniques during the voyage, not just at the destination.

Codifiable Knowledge

There are many uses and needs for the safe, long-term storage of codified knowledge that can be used during the voyage or even hundreds of years after landing at the destination. This sort of information can be encoded in a variety of ways using numerous materials and techniques, however it is essential to keep in mind that codified knowledge is worthless if it is encoded in such a way or form that is difficult or impossible to interpret. For example, a simple SSD may contain terabytes of information, but without a computer able to access, process, and display that information in a way that can be easily understood, the device is completely opaque (see *Level of Technology*). This requires a long-term storage solution that is durable, accessible, and decipherable (and ideally portable). To address these requirements, both microfiche and micro-etched glass stand out as portable transcription technologies that step up to the plate. For mid-long term storage, microfiche slides allow knowledge to be read in plain text from a nearly microscopic media using nothing but a lens and a light source. Similarly, micro-etched glass permits the reading of information with a relatively low level of technology. If this information is encoded, the portability can be in creased at the expense of simple decipherability. The authors envision a library of microfiche accessible to the ship inhabitants as well as a series of durable, ultra-long-term etched glass encyclopedias for use on planet to bolster the prosperity, advancement, and expansion of the prospective settlement.

Education

Compulsory schooling is important for many reasons. Beyond its role in peer socialization and rudimentary education, it functions as a childcare service for children of working parents, at least while children are young. When children grow and are more self-reliant, the beneficial role of schooling shifts to be more educational in intent. Ideally, a school provides an environment conducive to learning and lessons are taught by instructors who have an interest in educating others. In a small community that believes in education, we believe that these goals are not difficult to achieve and should be the baseline of performance for such a community.

The subject matter taught in compulsory education aboard the ship will naturally depend upon the ages of the children. Primary-school-age children should learn reading, writing, arithmetic, civics (including the values upon which the community is founded; see *Governance*), interpersonal skills, and history, which should give them a strong foundation for finding their place in their world. Secondary-school-age children should continue their studies in these fundamentals while also receiving additional instruction in science, epistemology, and survey courses in all the occupational areas aboard the ship. A rigorous education in science and epistemology should provide children with the tools they need to seek truth and shun demagoguery and populism, while the survey courses should expose children to areas of interest in which they may develop a passion and interest in pursuing. Education beyond secondary school should be self-directed and should focus on placement of young adults in areas where they may soon be occupied (ex: medical school, agriculture, public service, crafting, etc).

A culture that embraces learning as a virtue will undoubtedly reap many benefits. Schooling is not the only opportunity for education, and as such it should not shoulder all the responsibility for it. We envision a society that encourages curiosity and seeks to educate any curious person no matter their age. Such a society would not want for highly educated people and would be well-positioned to avoid knowledge loss. Such a society would not erect barriers to education, only bridges.

Death

Death is the constant companion of life. Based on agent-based simulations (see *Population Dynamics*), a healthy population of 1,000 - 1,500 individuals can expect to experience about 14-15 deaths per Earth year. Depending on the circumstances, death may be seen as the natural end of a life or an untimely tragedy, and this may be more true in a relatively small community considering the potential impact.

Impact

In an isolated community, news of death is likely to spread quickly for both personal and practical reasons. If the circumstances behind the death suggest that there might be an infectious disease, the medical community would have a vested interest, both in preventing the spread of illness and in furthering their education of human health and anatomy. If the death were the result of a preventable accident or an act of violence, the community would naturally have an interest in investigating the circumstances in order to prevent future occurrences of such a death. The people closest to the decedent are those most

I approached the secondary medical facility with hesitation, something I was not used to. This was not my first autopsy, nor would this be my last by far. This I knew for certain. I was sure that each of the fifteen or so trainees had their own ways of compartmentalizing this part of the medical education program, just as I had, however today was different. As I walked into the bright room lit from without and within, the grave-looking senior physician pulled me aside, hand on my shoulder. "You don't have to attend today," he said. "I think we'd all understand if you preferred to recuse yourself." I closed my eyes and turned my head down. I'd wanted to become a doctor for the longest time. So long that I don't remember a time when that wasn't my aspiration. I looked to the glass tile floor for just a moment before pursing my lips and returning his gaze. "Thank you doctor, but I've already decided." We walked to the autopsy table together, joining the rest of the trainees already present, each with an uncertain look on their faces. This would be the last thing I learned from my father. It's what he would have wanted.

in need. Support services such as grief counseling should be made available to all those in need.

Corpses

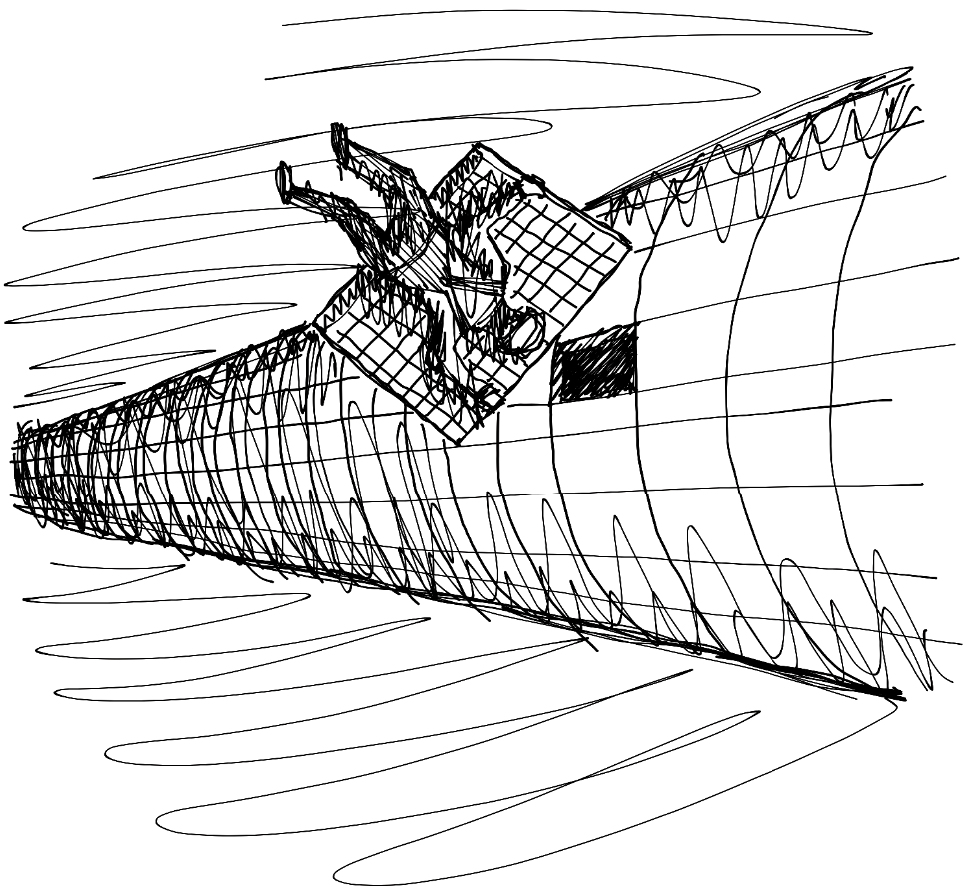
Death does not just remove a person from the community, it creates a corpse. Corpses must be dealt with swiftly and responsibly out of respect for the decedent and for the health of the public. Procedurally, the authority overseeing morbidity and mortality should certify and record the death and coordinate the subsequent logistics informed by the circumstances.

The corpse is not necessarily a liability though, and has much to offer in the way of knowledge for the medical community, specifically medical trainees. In such an isolated community, all corpses would likely be used to train the next generation of medical personnel though guided group necropsies. This is consistent with the shared cultural value of knowledge retention (see *Governance*) so we imagine there being a cultural expectation towards donating one's body for this purpose. Medical trainees could learn much from such an necropsy, including surgical technique, surgical medicine, and anatomy. After the necropsy, the corpse becomes a resource for the habitat. An efficient way to return these nutrients to the habitat is alkaline hydrolysis, which would effectively recycle most of the biomass in a way that can be used by plants as nutrients while retaining a small amount of bones that can be retained as material to be ceremonially buried at the destination.

Ceremony

The way in which death is observed changes over time and across cultures, and is shaped by many factors like mythos, religion, tradition, technology, environment, and practicality. The observance of death is also very personal, and may not be uniform even within a culture, just as beliefs about death are not necessarily uniform within a culture.

We imagine that the shared societal mission of establishing a settlement at the destination planet might lead to a tradition of retaining some remains of the decedent for burial at the destination or a similar ceremony. We also imagine that the inhabitants would develop a ceremony where the decedent is remembered and chronicled in some way, such as a public epitaph.



I remember back in school when they were teaching structural engineering, I got a little tidbit of Earth history as well. See, they wanted to teach about bridges, but there are no interesting bridges to talk about in our world, so they used this Earth bridge called the "Golden Gate" as an example. In-between discussing distributed loads and pinned connections and whatnot, the teacher mentioned that there was a painting crew whose sole job it was to start at one end of the bridge and paint until they got to the other side of the bridge. Supposedly when they finished, they started again right back where they started. In retrospect it sounds a bit apocryphal, but I'm reminded of it every time I'm up there changing out the modules on the Sunbeam. It's an ongoing project that tends to start at one end and continue to the other. I doubt those ancestral painters floated in the air while they did their job though...

The Technological Backbone:
Sustaining the Habitat and Society

Level of Technology

As argued in prior works discussing the considerations for crewed interstellar travel, there are several differences between local, intra-solar space habitats and interstellar generational ships, the latter lacking usable solar insolation, new raw materials, and a global supply chain. It is this last difference that carries the most abstruse conclusion.

Missiong Supply Chain

The manufacture of any technology relies on a supply chain of other materials and technologies. For example, a simple pencil requires technology for wood harvesting, saw milling, kilning, woodworking, mining, milling, extrusion, metal forging/electrolysis, metal stamping/shaping, rubber vulcanization, and adhesive chemistry, to name just a few. Moreover, each of these precursor technologies depends on its own subset of precursor technologies, ultimately tracing back to the most fundamental technologies such as the lever and the blade. Additionally, most technology must be maintained in order to function and components may need frequent replacement (especially for advanced technologies). The plentitude of the 8.2 billion individuals on Earth drives a global supply chain that underpins all the inputs required for the fabrication of everything from state-of-the-art semiconductors to the humble pencil. A population of 1,500 individuals cannot hope to replicate this supply chain. Without the ability to fabricate new units and replacement components, a technology will eventually fail.

Tacit Knowledge

As mentioned by Hein et al, a crew of limited size will have difficulty retaining and passing down tacit knowledge of the workings of many (if not most) technologies. Hein argues that this is due to a lack of redundancy in those possessing tacit knowledge, as smaller populations are more sensitive to random knowledge loss and such knowledge cannot be recovered. The more advanced the technology level of a society, the more individuals are needed to sustain it; put another way, the highest technological level a society is able to maintain is set in part by the population of said society. Without the population level required to provide redundancy in tacit knowledge of the technology used, high quality knowledge of that technology will ultimately be lost to the extent that the technology may not even be usable, and would certainly not be reproducible.

Exhaustive Redundancy

If we are to accept that necessary manufacturing supply chains and tacit knowledge of technology cannot be used to sustain or create technology onboard the ship or at the destination, one may consider the option of exhaustive redundancy. Such a solution may aim to provide enough redundant units and replacement components to provide for any and all equipment failures both during the voyage and at the destination. This, however, is time-bounded and is not a permanent solution. on a long enough time-frame, the spares will be depleted and the society would face the challenge of losing a technology that they had previously depended upon. Depending on the function of that technology, such a loss could be not only devastating, but could result in the death of the entire population. If mission success requires an indefinitely enduring society at the target destination, simply landing at the destination only to die out within a century due to technology loss should be considered a failure of the mission.

Use of Transitory Technology

The loss of an essential technology can be a lethal disruption to a society. Therefore, it stands to reason that in order to protect said society from lethal disruptions, the use of *Transitory Technologies* should be minimized. Here, a *Transitory Technology* is a one that is used by a society, but cannot be reproduced and/or maintained in the long run. In other words, a *Transitory Technology* is one that is soon to become a *Lost Technology*. There are two categories of transitory technologies that should be distinguished: mission-critical and non-mission critical.

Use of Mission-critical Technology

Onboard an interstellar generation ship, there exist mission-critical transitory technologies that are beyond the ability of a population of 1,500 individuals to sustain indefinitely. Such technologies include artificial sunlight, computers, interstellar engines, landing spacecraft, and nuclear energy, to name a few. During the voyage, these technologies are necessary for both navigating the interstellar void and simulating a planet-like environment for the crew to inhabit. Without a single one of these specific capabilities, the mission with the listed parameters would become unfeasible. Once living on the planet, however, these technologies would no longer be necessary and can be forgotten with little to no consequence for the burgeoning settlement.

Use of Non-mission-critical Technology

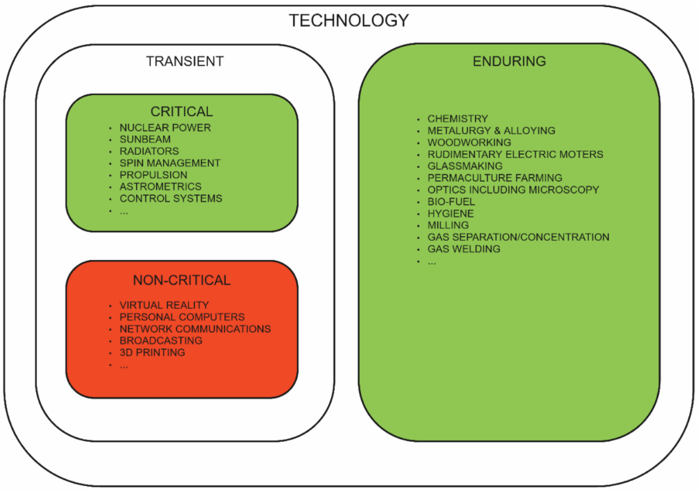
There are numerous examples of non-mission-critical transitory technologies that could be used aboard an interstellar generation ship. This category includes convenience technologies that do not provide essential functionality (such as entertainment) as well as sustenance technologies that do provide essential functionality (such as agriculture) but could be performed by more-fundamental technologies. An example of the latter would be vertical farming technology, which can provide a critical function despite the fact that such a technology could not be maintained by a small society and could be replaced by permaculture-type agriculture instead. Like any transitory technology, it would only be a matter of time until the society loses these technologies.

It may seem that the loss of a convenience technology does not represent a serious event for the crew, however, such a loss may have downstream social consequences that could negatively impact morale and the crew's perception of their long-term stability and self-sufficiency. The loss of a technology, even one deemed non critical could trigger feelings of vulnerability and foster anxiety about the crew's ability to address future challenges.

It may also seem that the loss of even a sustenance technology is not a major issue so long as the society has a more-fundamental backup technology they can use to fill the void. There are a few issues with this thinking, however. Firstly, this assumes that the society has indeed retained knowledge of the backup technology. The retention of this knowledge across multiple generations is difficult enough for such a small crew and is even more precarious when the knowledge in question is not in constant practice or requirement (see *Knowledge Retention*). The individuals in the society may also come to decide naively that they no longer need the tacit knowledge of a backup technology. Secondly, the loss of sustenance technology carries the same negative social consequences as the loss of convenience technologies, only more pronounced. Lastly, if the society could persist after having lost a certain sustenance technology (replaced with a backup technology), there seems little purpose in starting with the more advanced transitory technology in the first place considering the additional risk and resource expenditure and the result being a society that must use the more-fundamental technology anyway.

Prescription

Any technology that stands to fail between the time of launch to several hundred years after the time of landing has no place in this societal design. While some technologies carry the promise of improving the quality of life of the population, said population would be highly likely to depend on such a technology at the expense of retaining living knowledge of more enduring technologies. This is a risky proposition as the sudden failure of a technology that a society has come to depend upon can spell disaster as there may be no other technology in living memory that can substitute for that need.



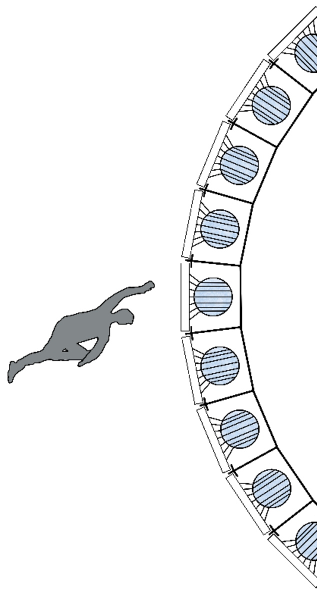
For these reasons, the approach of this submission is to limit the technology chosen for this journey to: mission-critical transitory technologies and self-sufficient technologies. Mission-critical transitory technology is feasible as it is both necessary for the journey as well as time-bounded, meaning that replacement components could be supplied to last the duration of the transit. Self-sufficient technology is the most-likely knowledge to be retained as it is both necessary and maintainable by a small society. As a consequence, such a society might appear somewhat more provincial or even archaic to an individual of the 21st century, let alone the 22nd or 23rd centuries. This should not be considered a permanent setback however, as the scientific knowledge of advanced society can still be retained by the inhabitants in codified form (see *Knowledge Retention*). Armed with this knowledge, the technological advancement of such a society, once established, will likely exceed our own historic pace of advancement.

It is our opinion that if an isolated settlement's survival is dependent on technology it cannot replicate, that population will ultimately fail.

Habitat Engineering Systems

Sunbeam

One of the most important mission-enabling technologies is the lighting technology that can simulate the sun onboard an interstellar vessel. In this submission, this technology takes the form of the Sunbeam. This structure lies at the literal center of the society tracing the axis of rotation of the habitat. It is a hollow tube-like structure completely lined on the exterior with high-power LED modules designed to replicate the full spectrum of sunlight. While a structure like this has been conceived of before, this one may be unique in that only parts of it are active at any given time. In the morning, one end of the sunbeam starts to brighten, and along the course of the day, via brightening and dimming modules, the sun travels across the sky until setting at the other end at the end of the day.



Such a dynamic sun bestows many advantages. A moving sun has a better capability to provide adequate lighting to ground-covering foliage that may otherwise be shaded. A moving sun also heats different parts of the habitat at different times, which helps to generate the temperature differences that aid in creating dynamic breezes. Most significantly for the inhabitants, the dynamic nature of lighting over the course of a day carries significant psychological benefits.

The modules of the Sunbeam are meant to be serviced by way of replacing malfunctioning modules (likely during the night). This can be accomplished by traveling up the endcaps towards the center and simply floating to the destination of service (ideally at night). Cooling of the modules is meant to be facilitated by a combination of the air that is forced to the center (see *Wind* and *Dehumidification*) and cooled water diverted from the fusion reactor thermal cycle cooling loop (see *Assumptions*).

We estimate that the Sunbeam will consume 96.6% of the energy demand of the habitat, which amounts to over 50,000kWh per day.

Dehumidification

Humidity is a surprisingly serious concern in such a habitat design. This is because the terrestrial factors that remove humidity from the air are not all present. For example, hot, humid air may rise (against gravity) on Earth and would eventually reach the cooler environment of the sky where it would condense into clouds. By contrast, in a habitat that lacks a cool sky (and having the Sunbeam in located in the center), there is no opportunity for humidity to be condensed into clouds (let alone for said clouds to rain).

In our habitat design, humidity control is achieved through a network of large, integrated grids that work in tandem with a coolant loop. As warm, moist air is forced through the passageways that slow the air (see *Wind*), it passes through these grids where the coolant's lower temperature causes water vapor to condense into droplets which are then recovered and returned to the habitat. This process is analogous to the natural formation of dew but on a much larger, engineered scale. The design leverages the coolant's natural phase change—from liquid to gas—as it absorbs heat, thereby eliminating the need for mechanical pumps. The resulting vapor is then channeled into external fin structures and directed into hydrogen tanks, where it aids in further thermal management. This system not only maintains a comfortable and stable internal environment but also enhances overall efficiency by minimizing energy consumption and mechanical complexity.

We estimate that forcing the air through the fans will consume 0.047% of the total energy demand of the habitat, which amounts to 240kWh per day.

Heat Rejection

The heat rejection strategy is designed to complement the dehumidification process by efficiently removing excess thermal energy from the habitat. Once the coolant has absorbed heat during its passage through the interior environment, it is routed through an extensive network of fin radiators that cover the outer shell of the vessel. These radiators increase the surface area available for heat transfer, ensuring that the absorbed energy is effectively radiated away. The radiator fins attached to the habitat are interlaced with non-rotating, radiation-absorbing fins attached to the shell of the ship. The absorbing fins transfer the heat through a layer of hydrogen fuel via insulated conduction rods to the exterior surface of the ship (which is held at a much hotter temperature than the fuel) to be radiated into interstellar space.

By integrating both the fin radiators and the hydrogen fuel layer (see *Radiation Shield*) into the heat rejection process, the system provides a robust, passive cooling mechanism that minimizes reliance on energy-intensive components. This approach supports the habitat's long-term thermal stability and aligns with our overall emphasis on efficient engineering practices.

Radiation Shield

Interstellar space is inherently hazardous due to the persistent presence of high-energy galactic cosmic rays (GCR). These high-energy particles can permeate the habitat and, without mitigation, would severely impact both biological and electronic systems over time. Inhabitants exposed to unattenuated GCR face elevated cancer risks and acute radiation sickness, while critical habitat subsystems would accumulate damage, precipitating a catastrophic collapse of shipboard operations.

To ensure long-term mission viability and crew health, Neo-Genesis Seed employs a multi-layered approach to radiation protection designed to attenuate both primary GCR and secondary particle cascades:

Liquid Hydrogen Shield (integrated fuel layer):

A several-meter thick layer of liquid hydrogen envelops the ship's exterior and ties directly into the main propulsion fuel tanks. Hydrogen's low atomic number and high nucleus density make it one of the most mass-efficient materials for attenuating high-energy particles. By integrating this shielding with the fuel system, Neo-Genesis Seed obviates redundant radiation shielding mass, leveraging the same mass for dual propulsive and shielding functions.

Terrain Barrier (ecosystem shell):

Encasing the habitat core is a multi-meter layer of engineered terrain—soil, rock aggregates, and biocylinder substrate—originally intended to support the onboard ecosystem. This outer shell also serves as a secondary shield: any GCR particles that penetrate or otherwise circumvent the liquid hydrogen layer may induce harmful secondary neutron radiation upon interaction with the structural shell. The thick terrain barrier is well-positioned to attenuate this radiation, further reducing radiation flux to safe levels for both crew and sensitive systems.

Hydrology

Rain is not possible in a habitat of this size, and perhaps not even for a habitat of ten times the size. One obstacle is cloud-formation; clouds require cool air in order for water to condense out of the air which is not possible in an environment where most of the heat is coming from the central Sunbeam. Another more fundamental challenge is the path of water. Rain cannot be released from clouds in a gravity-free environment as exists in the center of this habitat. Even if water could be released from the center towards the perimeter of the habitat, this would not result in vertical rain, but rather sideways rain that may not even make it all the way to the lower areas. This is because the rain, once released, has a ballistic trajectory while the ground underneath has a trajectory of centripetally accelerating tangential motion.

Our hydrology system is designed to replicate a natural water cycle within the habitat through the use of large-scale water pumps. These pumps extract water from depressions at lower elevations and mechanically convey it to higher reservoirs, effectively simulating the natural processes of runoff and precipitation. This engineered circulation supports critical ecosystem functions such as irrigation and nutrient distribution, while maintaining a balanced water supply throughout the habitat.

Simultaneously, water transported from these lower areas where it may gather hazardous chemicals like NOx from agricultural runoff, undergoes an integrated filtration process. The system utilizes catalytic reactions and freeze-separation techniques to efficiently remove contaminants. Both the pumps and the filtration units are designed for simplicity and ease of maintenance, given their mission-critical role in sustaining water quality and overall environmental stability.

We estimate that the water pumping system will consume 2.96% of the total energy demand of the habitat, which amounts to 1,550kWh per day.

Evaluation Criteria Satisfaction Matrix

Evaluation Criteria	Design Response/Reference
Logical integration of form, function, and aesthetics (Architectural Quality): Competitors must elucidate how the chosen volumes' forms functionally or aesthetically align with their core concepts.	The form, function, and aesthetics are elucidated throughout the document, with particular explanation given in the section entitled **Habitat Form**.
Flexibility and modularity: Given the ship-city's multi-generational use, the modularity of designed spaces holds significance. Competitors must elaborate on the reasons and methods for incorporating flexibility and modularity into their designs.	The form, function, and aesthetics are elucidated througho Architecturally, the open, exterior-simulating nature of the habitat lends itself to flexibility (see **Environment**), while the pliable nature of the governance structure allows for social change over the life of the mission (see **Governance**).
Innovation & Technology: These factors are pivotal, and their influence on architectural design must be clearly defined.	The section entitled **Level of Technology** elucidates our reasoning for our design decisions made with regard to technology used by the inhabitants. Furthermore, our engineering-related sections delve into the mission-enabling technology that will make this mission possible.
Graphic quality: Deliverables should be presented in clear and comprehensible architectural graphic design.	The main sectional diagrams describe the main components of the architectural design at the habitat scale.
Gravity: The habitat shall provide Earth gravity via artificial gravity via rotation but parts of the habitat can have reduced gravity.	As can be seen in our main sectional diagrams and our section entitled **Gravity**, we have taken care to ensure access to Earth-like gravity in the main inhabited areas of the habitat. In addition to the open-concept drum form, the convex areas of the endcaps permit the experience of reduced and even zero gravity.
Protection: The habitat shall provide radiation protection (predominantly protection from Galactic Cosmic Rays) as well as micro meteorite and interstellar dust protection.	As can be seen in our main sectional diagrams, fuel tanks exterior to the habitat provide ample radiation protection without contributing undue additional mass to the ship system.
ECLSS: The habitat shall provide environmental control and life support: How are essential physical needs of the population provided? Food, water, air, waste recycling. How far is closure ensured?	The sections entitled **Ecosystem** and **Environment** speak to the role the constructed and living systems play in regulating the life-sustaining attributes of the habitat. Redundancy and robustness are key elements to our approach.
Ecosystem: The ecosystem in which humans are living shall be defined at different levels: animals, plants, microbiomes.	The section entitled **Ecosystem** describes our intent with regard to the living systems and the role they play in the habitat.
Mass: The mass of the habitat shall be as low as possible.	We have included a first-order mass budget in the section entitled **Habitat Form**. It is our position that mission success should be valued over mass efficiency and that an overly lean approach to this mission design jeopardizes the entire endeavor.
Realistic multigenerational design considering the departure, travel and arrival population	The section entitled **Population Dynamics** speaks to the designed capability of the cultural system to behave with regard to the multigenerational nature of the journey.
Capacity for the biocultural system to adapt to change over time	As laid out in the section entitled **Governance**, the societal structure (as well as the interdependent biological structure) is able to change over time through the direct and democratic action of the inhabitants.
Commentary on some expected changes to biology and culture over multiple generations	The section entitled **Governance** suggests possible ways in which the culture may change/adapt over time (for better or worse), however it is our position that this society is unlikely to experience much biological change over only 7-13 generations.
Power Budget	The **Sunbeam**, **Dehumidification**, and **Hydrology** sections detail the power/energy estimates for these systems.
Brief story or narrative elements describing the life of inhabitants.	The head of each section throughout this document includes a brief narrative vignette of various aspects of life within the habitat.