Australian Space Design Competition
Regional Qualifying Competition 2020-2021

REQUEST FOR TENDER
30 March 2065

"Benevectoras" Space Settlement Contract

INTRODUCTION

The Foundation Society seeks proposals for the second space settlement in solar orbit, an Aldrin cycler orbit crossing the orbits of Earth and Mars, and serving as a transportation system for cargo and passengers between the planets.

Organised cis-lunar economic development started in 2023 with formation of the Space Enterprise Applications Consortium (SEAC), formed by legacy space contractors and NewSpace companies to pool corporate resources for development of space infrastructure. The companies turned to the Foundation Society--then a venture capital investor organisation funding entrepreneurial space tourism launch vehicles--to lead SEAC projects. NASA partners turned over International Space Station (ISS) ownership to SEAC, which renamed it Spaceport Freedom and added Low Earth Orbit (LEO) spaceports Liberty and Independence to serve as transfer ports for exports, imports, and passengers between Earth and space. SEAC partners adapted existing designs for ISS components and from unbuilt proposals to quickly produce new launch vehicles, space tugs, orbital depots, transfer vehicles, lunar landers and rovers, and bases at mining sites on the Moon. The original products that justified cis-lunar economic development were propellants from lunar resources to refuel existing satellites, and satellite servicing and repair.

Anticipating that large quantities of cargo would be shipped around cis-lunar space, the Foundation Society established a standard for space cargo containers that all SEAC members agreed to be compatible with their launch and space vehicles. Cargo Accommodation in Standard Space Shipping Container (CASSSC) units are 30 feet (9.144 meters) long with nearly-square 15-foot (4.572 meters) cross-sections, allowing up to 35,000 pounds (15,876 kg) of contents.

The Foundation Society invested in a new habitat for refining of ores and on-orbit manufacturing, declared it the first permanent human settlement in space, and named it Alexandriat. At this first and every subsequent Foundation Society habitat and settlement, crews were encouraged to tinker and experiment with materials and processes in space environments. They represented the largest pool of unscheduled hours ever experienced in space. Their creativity quickly resulted in establishing a bevy of in-space capabilities and start-up companies that became subcontractors.

The Foundation Society and SEAC partners aggressively pursued utilisation of extraterrestrial resources to produce products both for use in space and export to Earth. The large settlements they operate now include Alaskol on Earth's Moon, the Bellevistat industrial settlement at L4, Atlas that moves asteroids to L4 for harvesting at Bellevistat, and the Columbiat banking and commerce centre at L5. Lunar materials are shipped by mass driver from the lunar surface, and personnel go to and from the Moon via the space elevator at the L1 port, Arial. Expanding economic activity in cis-lunar space increased demand for launch services, and increasing flight rates result in lower launch costs. Launch costs from Earth to LEO are now as low as $400,000 per person (120 kg allowance for person and possessions) and $1500 per kg of cargo.

With the cis-lunar economy established, the Foundation Society and SEAC are now looking at expanding economic activity to Mars. The cycler settlement will grow and re-purpose as Mars infrastructure and population grow. After Initial Operational Capability (IOC), construction to grow the settlement will continue as it cycles between Earth and Mars. During these assembly orbits, near-Mars passes will focus on bringing more cargo than people. At operational capability, it will be the primary transportation vehicle for Mars settlers. When fusion propulsion enables faster transits to Mars, people will travel on the faster ships and the cycler will mostly carry cargo.

For planning purposes, the Foundation Society selected "Benevectoras" as this settlement's name, based on the Latin words "bene" for doing something in a good way, and "vector" for a carrier or bearer. The name acknowledges that the settlement will be an efficient transportation system between Earth and Mars.

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STATEMENT OF WORK

1. **Basic Requirement** - Describe the design, development, construction, and operations planning for an Aldrin cycler providing efficient transportation between Earth and Mars.

2. **Structural Design** - At IOC, Benevectoras must provide a safe and pleasant living and working environment for a population of 500 full-time residents, and 1300 settlers in transit to Mars. At each subsequent near-Earth pass, add capability to increase full-time population by 500, and in-transit Mars settlers by 1000, until reaching operational population of 2500 full-time residents and 6300 in-transit Mars settlers. The design must enable residents to have access to windows for natural views of space outside, and of Earth and Mars when they are nearby.

2.1 On exterior design drawing(s), identify uses of large enclosed volumes in the operational configuration, and show dimensions of major structural components and design features. Provide artificial gravity of 0.38 g in living areas. Specify structural interface(s) between rotating and non- rotating sections; both sides of rotation interface(s) must have the same atmosphere conditions.

Minimum requirement: overall exterior views of settlement, with major visible features (e.g., solar panels, antennas), showing rotating and non-rotating sections, pressurised and non-pressurised sections, and indicating functions inside each volume (e.g. port, warehousing, and residential areas).

2.2 On interior configuration drawing(s), specify uses and dimensions of interior "down surfaces", with areas allocated and drawings labelled to show residential, industrial, commercial, agricultural, port facilities, community services, and other uses. Show orientation of "down surfaces" with respect to overall settlement design, and vertical clearance in each area.

Minimum requirement: overall map or layout of interior land areas, showing usage of those areas.

2.3 Describe processes required to construct the settlement, by showing the sequence in which major components will be assembled. Specify when and how artificial gravity will be applied. Describe construction of interior structures. CASSSC units delivered during construction may be converted to interior structures.

Minimum requirement: drawing(s) showing at least three steps of settlement assembly to IOC, and configuration at each near-Earth pass during assembly orbits.

2.4 Provide a port/base for a fleet of space tugs that will manoeuvre Benevectoras into the Aldrin cycler orbit at IOC, provide course corrections as needed, and transfer cargo and passengers to and from the settlement during passes near Earth and Mars. On overall exterior drawing(s), show where tugs push on the settlement structure to establish and adjust the cycler orbit.

Minimum requirement: drawing(s) of dock configuration(s), including ships in port.

2.5 Show where and how en-route manufacturing and assembly capability is added at each pass near Earth. Most commodities will be made in pressurised volumes, and most Mars infrastructure components will be made in vacuum.

Minimum requirement: show locations of manufacturing areas on exterior view and internal map.

3. **Operations and Infrastructure** - Describe facilities and infrastructure necessary for building and operating the Benevectoras space settlement.

3.1 Specify an orbital location where Benevectoras will be constructed to IOC. Identify sources of materials and equipment that will be used in construction and operations, using minimally refined extra-terrestrial materials as much as possible. Transportation costs are reduced by shipping in CASSSCs. Show how components that must be shipped will be packed in CASSSCs.

Minimum requirement: table identifying where component parts will be manufactured.

3.2 Benevectoras' design will show elements of basic infrastructure required for the activities of the settlement's residents, including (but not limited to):

- food production (identify locations of agricultural areas, and growing conditions)
- electrical power (specify total kilowatt-hours generated, stored and distributed)
- internal and external communication systems (specify devices for personal use)
- internal transportation systems (show routes and vehicles, with dimensions)

- atmosphere (identify composition and quantity, at 65% pressure of Earth sea level and 71°F / 21°C)
- household and industrial solid waste management (specify recycling and/or disposal)
- water management (specify required water quantity and storage facilities)
- day/night cycles (show how sunlight will be "turned on and off" in community areas).

Define quantities of initial supplies of air, water, food, transport vehicles, power equipment, and other commodities as the number of CASSSC-loads required to be delivered for each commodity. It is preferred that air, water, other commodities, and standard infrastructure components be supplied by subcontractors.

Minimum requirement: chart(s) or table(s) specifying CASSSC-loads required of commodities.

3.3 Show designs of primary machines, jigs, and equipment employed for constructing the settlement, especially for assembling exterior hull and interior buildings / structures using standard components. Specify which of these assets will be used for IOC vs. operational construction. Show how construction machinery, jigs, and tools are shipped to the IOC construction site.

Minimum requirement: drawing(s) of primary construction machinery, showing how it shapes and/or manipulates raw materials or structural components into finished form.

3.4 Specify the numbers and type(s) of tugs based at Benevectoras at each near-Mars pass. Show a notional tug design based on requirements determined from Appendix A, and how CASSSCs are warehoused prior to and after transfer on tugs at Earth and Mars.

Minimum requirement: show size(s) of tug(s) required to transfer identified numbers of CASSSCs.

3.5 Advise what infrastructure for Mars can be manufactured on Benevectoras and brought to the planet at each near-Mars pass, including (but not limited to) rovers and aircraft. Items to be used on Mars surface must be shipped in CASSSCs.

Minimum requirement: list items to add infrastructure in Mars orbit and on the surface.

4. Human Factors and Safety - Benevectoras will provide facilities for services that residents expect in comfortable modern communities (e.g., housing, entertainment, education, medical, parks and recreation), variety and quantity of consumer goods, and public and residential areas designed with open spaces and long lines of sight. Assure that natural views of space outside are available.

4.1 Public living areas will include office and government buildings, meeting spaces, other community services, and agriculture as part of greenspaces. Living areas (including residential, commercial, retail) will have pressurised vertical clearance of at least 250 feet (76 meters) outside of and above buildings. Show locations and relative sizes of buildings and facilities.

Minimum requirement: map(s) and illustration(s) depicting community design and locations of amenities, with a distance scale and dimensions of major features.

4.2 Include floor plans of typical homes, clearly showing room sizes; home designs for permanent residents will be no smaller than 100 m^2; homes for in-transit Mars settlers can be smaller. Show on a community map where homes for permanent residents and in-transit Mars settlers will be located.Anticipated demographics of the original population are:

- Married adults 60% (average age 37, median age 34)
- Single Men 21% (average age 33, median age 32)
- Single Women 17% (average age 35, median age 30)
- Children (under 18) 2% (average age 6, median age 5)

Minimum requirement: external drawing and interior floor plan of at least four home designs, the area (preferably in square metres) for each residence design, and the number required of each design.

4.3 Provide capability to isolate multiple habitable volumes in case of emergency. Specify spacesuit features, types, and quantities required to enable work outside of pressurised volumes; and safety systems enabling human inspection and repair of exterior surfaces of rotating volumes. Show locations of airlocks between habitable areas and unpressurised volumes, and between interior volumes that can be isolated. Provide protection from radiation and severe solar flares.

Minimum requirement: identify in overall design separate volumes that can be isolated.

4.4 Identify and estimate quantities of daily-use commodities to be made on each orbit, both for Benevectoras residents and shipping to the growing settler population on Mars. Show where commodities are made and stored, and how Mars-bound commodities will be transferred to tugs.

Minimum requirement: list of commodities to be manufactured on Benevectoras.

4.5 In-transit Mars settlers will want to continue involvement in their careers and businesses en route, and may want to manage preparations for starting new businesses at Mars.

Minimum requirement: show on interior map(s) where offices are located for in-transit settlers.

5. Automation Design and Services - For each subparagraph, specify numbers and types of computing and information processing devices, multi-function personal electronic tools, servers, network devices, and robotic applications required for facility, community, and business operations. Describe types and capacities of data storage media, data security, and user access to computer networks. Define robot functions, quantities of each robot type, and locations where they operate.

5.1 Describe uses of automation for construction. Show appropriate automation systems to assist with transportation and delivery of materials and equipment, assembly of the settlement, installing utilities and infrastructure, and interior finishing. Describe how humans monitor automated construction processes and progress, and where/how human interaction is required during construction. Show how jigs hold robots in position to perform construction tasks in zero g.

Minimum requirement: dimensioned drawings showing automated construction and assembly devices, showing how they operate, and systems enabling human intervention, including displays for monitoring and control.

5.2 Specify automation systems for settlement maintenance, repair, and safety functions; show how automation works together with humans to perform these tasks. Describe when and how human intervention in automated functions is required. Describe means for authorised personnel to access critical data and command computing and robot systems; include descriptions of security measures to assure that only authorised personnel have access, and only for authorised purposes.

Minimum requirement: chart, table, or list(s) of settlement systems and parameters that must be monitored and controlled for safe and productive operations of Benevectoras. Show illustration(s) of control room for settlement monitoring and control.

5.3 Show automation devices to enhance liveability in the community, productivity in work environments, and convenience in residences. Emphasise use of automation to perform maintenance and routine tasks, and reduce requirements for manual labour. Describe access to community computing assets and robot resources from homes and workplaces. Robots encountered in daily community life will be no taller than four feet (122 cm), and not anthropomorphic. Provide for privacy of personal data and control of systems in private spaces. Describe devices for personal delivery of communications services, entertainment, information, computing, and robot resources.

Minimum requirement: dimensioned drawings of robots, drones, and computing systems that people will encounter in Benevectoras, and diagram(s) of network(s) to enable connectivity.

5.4 Provide automated loading and unloading of CASSSCs in the tug port. Show the control centre(s) for the tug fleet, and how it changes as tugs are added after IOC.

Minimum requirement: show size(s) / location(s) on interior map(s) of tug fleet control centre(s).

5.5 Describe where and how automation is used in manufacture and transportation of commodities and Mars infrastructure items.

Minimum requirement: list of automation system types employed in manufacturing areas and logistics operations.

6. Schedule and Cost – The proposal will include a schedule for development and occupation of Benevectoras, and costs for design through construction phases of the schedule.

6.1 The schedule must describe contractor tasks from the time of contract award (1 October 2065) until the customer assumes responsibility for operations of the settlement at IOC. Show schedule date(s) when Foundation

Society members may begin moving into their new homes at IOC, and when the entire original population will be established in the community at completion.

Minimum requirement: durations and completion dates of tasks from design to occupation, depicted in a Gantt chart with monthly increments.

6.2 Specify costs billed per year from design through construction in Australian dollars, without accounting for economic inflation. Estimate numbers of employees working during each phase of design and construction in the justification for contract costs to design and build the settlement. Do not include costs of consumables shipped and delivered in CASSSCs; do specify number of CASSSC-loads of each commodity required to be shipped to the construction site.

Minimum requirement: spreadsheet(s) listing separate costs associated with different phases of construction, and clearly showing total costs that will be billed to the Foundation Society.

7. Business Development – Commercial ventures will initially focus on three business areas. Mars has raw materials that settlers need; one thing lacking for Mars settlers is unallocated time, so permanent residents and in-transit Mars settlers can occupy between-planet time with making consumables and building components for Mars infrastructure. Transfer times from Earth to Mars will vary from six to nine months; from Mars to Earth vary from eight to fourteen months. Initial business pursuits are (this proposal section may reference designs in other paragraphs):

- Port for space tugs
  - Space tugs that will maneuver Benevectoras into the Aldrin Cycler orbit, do course corrections, and transfer people and cargo to/from ports in orbit around Earth and Mars will be based at Benevectoras in zero-g docking facilities.
  - Opportunities for transferring passengers and cargo may be limited to only eight days at Earth and Mars; docking facilities and the tug fleet must enable rapid unloading and loading, and numerous trips during transfer opportunities.
  - Passenger and cargo terminals must enable safe and convenient transfer between the artificial gravity environment and spacecraft in zero g.
- Manufacturing commodities for use on Mars
  - Provide excess capacity for manufacturing commodities (e.g., agricultural and household products) to augment supplies on Mars.
  - Specify quantities and types of agricultural products that can be transferred to Mars; show how agricultural products are loaded in CASSSCs for transport to Mars.
  - Specify quantities and types of household products that will be manufactured on Benevectoras for use on and near Mars; show how household products are loaded in CASSSCs for transport to Mars.
- Manufacturing for Mars infrastructure and trade with Earth
  - An increasing population on and near Mars will need more infrastructure to grow the Martian economy. Identify items that can be built or assembled en route between Earth and Mars, and components or raw materials required for manufacturing.
  - Mars minerals with unique properties can be marketed for cis-lunar and Earth use. Income is made on trips to Mars; return is almost free, so Mars product costs can be competitive for cis-lunar use. Provide refining of Mars ores into useful materials.
  - Deuterium is relatively plentiful on Mars, and will be combined with lunar helium 3 to power future fusion ships. Provide tank capacity for transporting deuterium to Earth.

8. Appendices – required to be included in the proposal, but do NOT count against the 50-page proposal limit.

A. Operational Scenario – conduct a Trade Study to determine number(s) of tugs and transfer vehicles based at Benevectoras. Show factors and scoring methodology to determine whether one or multiple types of vehicles are needed, how many are needed, docking system(s), and number(s) of CASSSCs and/or passengers that can be accommodated on each vehicle type.

B. References – cite references used in proposal preparation. Any text or image that is not an original creation specifically for this proposal must be specifically referenced to source materials included here.

C. Compliance Matrix – include a table that at minimum lists each requirement in the SOW, and specifies the page(s) in the proposal where that requirement is addressed.

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EVALUATION CRITERIA

Evaluation of each design presentation considers four general categories of factors:

- **Thoroughness** - Design meets depth and diversity of requirements in the entire SOW. Graphs, tables, drawings, and compliance matrices aid evaluation of this factor.
- **Credibility** - Design addresses requirements, safety, physical laws, and cost/schedule in a believable manner. Errors, impossibilities, omissions, and illogic are penalised.
- **Balance** - Proposal places equal emphasis on four technical areas: structural design, operations, liveability, and automation. Proposal is organised in a logical, easy-to-follow manner.
- **Innovation** - Design demonstrates original thinking to address SOW requirements. Technologies are applied and combined in unique and creative ways.

ADDENDA

Proposals may suggest alternate names for this community, within the Foundation Society's established naming convention that requires the name to begin with the letter "B" (second settlement at an "as" location) and end with the suffix "as" (settlement is in orbit “around Sol”).

DELIVERABLE REQUIREMENTS

Teams shall develop a proposal in accordance with the following:

Report
- Submissions shall be in the form of a technical report
- A maximum of fifty (50) pages (including Appendices) may be submitted
- Use a standard font (e.g. Arial, Calibri, Times New Roman)
- Pages must be clearly legible when printed in black-and-white on A4 paper
- Reports are not to include student details or name of school
- Include the team’s registration number on report cover page

Measurements and Values
- All measurements shall be in standard engineering metric units, except where specified by the RFT
- All values and budgets shall be in AUD as at January 2020 and shall not consider economic inflation.

Diagrams
- All diagrams must be appropriately captioned
- All diagrams must be appropriately dimensioned unless specified as artistic impressions

Tables and Figures
- All tables and figures must be appropriately titled

References
- All attributable content including, but not limited to, diagrams, research, and text must be appropriately and uniformly referenced
- The reference list is not included within the 50 page limit
- Use your school’s preferred reference style (e.g. Harvard, APA, MLA, Chicago etc.)
- Declare which reference style you have used

Submission
- Entries must be submitted electronically (PDF) 5pm on 21 August 2020
- Submissions to occur through a file upload link on the ausspacedesign.org.au website (subject to confirmation)

SUBCONTRACTORS

Major companies have access to a vast network of smaller companies making specialised products. They are eager to make or do anything they are capable of making or doing, for anyone who will pay. They frequently have contracts with competitors for the same proposal. These include:

3D Logistics successfully 3D printed tools and components from a variety of feedstock materials at spaceport Freedom, and now has a production facility at Alexandriat. The company developed a 3D printing system that is flown on crewed spacecraft to enable replacing failed parts, eliminating most of the need for on-board logistics inventory.

BeamBuilders, Ltd. is a European company which operates an automated manufacturing facility on a ferro-nickel asteroid in an Earth-crossing orbit. The company produces triangular trusses to customer-specified dimensions, at the rate of 500 linear feet per hour. Customers are required to provide their own transportation of these structures, although some limited assembly is permitted in the vicinity of this operation; orbital mechanics restricts practical delivery opportunities to twice per year. The company's standard triangular truss with 12-foot sections, suitable for zero-g installations, typically sells for $1500 per linear foot. Custom orders are more expensive.

Blown Away specialises in making inflatable buildings per customer specifications, to enable quick construction of new communities on the Moon and in space. Although these structures are not intended for permanent or indefinite use, they provide shelter for residents to start new economic activities, until more durable solutions can be established. The company also has a product line of inflatable furniture, cheap to ship and simple to set up.

Bots4U offers purpose-built robots for home and office use. Currently available functions for robots are cleaning household surfaces, washing dishes, doing laundry, moving furniture, and fetching and stowing items for their owners. The company offers to build robots to customer specifications for space applications; robots built for use on Earth perform adequately in 0.38 g.

Bottom Cleaners recognised a critical need for long-term space habitation, first discussed in public at an NSS Space Settlement Summit in 2017: toilet paper. A system adequate for continuously supplying toilet paper for 1000 people fits in one CASSSC, and can be installed anywhere in a pressurised volume where power and water service are provided. The facility makes toilet paper out of plant fibers collected from agricultural and landscaping waste. Excess capacity can be used for making paper towels and other household paper wiping / absorbing products.

BuckyBreakthroughs developed generic versions of silicon buckystructure applications when patents expired. The material is a form of lunar silicon resembling the structure of carbon nanotubes. It is extraordinarily strong in tension, tolerates the space environment, and can be formed into flexible strands and cables of unlimited length, or vast nets and sheets of fabric. Colors range from milky white to quartzlike transparency; properties of different forms and with various introduced impurities include thermal insulating qualities, electrical conductivity, sound transmission, adhesion, or light refraction. One variant is a bright white fabric that prevents penetration by space debris up to two inches in diameter (but offers no thermal insulation). The company was the first to develop windows made from silicon buckystructure materials for use on space structures. Windows can be ordered in any shape. With proper sealing, standard windows with no dimension greater than 3 ft. (91 cm) can retain up to 1 Earth atm pressure. If never exposed to direct sunlight, windows provide adequate radiation protection and thermal insulation.

Carbon Creations collaborates with Waste Products and Toss It To Me to receive carbon from their lunar installations, from which it makes useful products ranging from fuels to plastics. The company is also researching forms of silicon buckystructure fabric and carbon-based resins that can be used to make a rigid product similar to--but stronger and more durable than--fiberglass.

Clean Up Your Act recycles water from cleaning, kitchens, and agriculture, and delivers potable water back into space communities' safe water supply. The company also advises communities on maintenance of proper atmosphere composition, and provides air revitalisation when CO2 or other atmosphere components go out of balance. The company has an agreement with Waste Products that it can install its infrastructure simultaneously with installation of sewer lines.

Custom Cargo Accommodations produces Cargo Accommodation in Standard Space Shipping Container (CASSSC) units, compatible with standard interfaces in launch vehicles and interorbital spacecraft currently in use. CASSSCs are 30 feet (9.144 meters) long with nearly-square 15-foot (4.572 meters) cross-sections (corners of the cross-section are rounded with a 1-foot radius). Generic CASSSCs are aluminum, fully enclosed, and vented to permit pressure equalisation. Special-order CASSSCs can be whatever customers choose within standard size and interfaces constraints, including pressurised, open framework, or made of composite materials.

Dirtbuilders has contracted with CalEarth (calearth.org) to be the supplier of SuperAdobe casings and robotic assemblers for extraterrestrial applications. The company makes casings for lunar and orbital applications from silicon buckystructure fabric. In lunar gravity, SuperAdobe structures can be built up to 70 feet (21.34 m) high and 50 feet (15.24 m) in diameter.

Drone & Delivery provides small self-driving air and ground vehicles for use in pressurised volumes of space settlements and habitats. Applications of aerial drones are primarily transportation of small items and inspections in industrial and agricultural areas; small ground vehicles provide similar services in residential and commercial areas.

ElectroProtect builds components for circuitry that can withstand space environments, and shielding or protective boxes for components, circuits, electronics, computing equipment, and robotics that cannot be built to withstand local environments.

Extreme Survival Technologies (EST) builds spacesuits, pressurised fabric impact protection systems (e.g., airbags and restraints), and portable emergency shelters. Its most popular products are hard-shell spacesuits customised for lunar operations but frequently used for other applications; efficiencies of assembly line production enable $400,000 unit costs.

Fusion Founders serendipitously happened upon an apparently ideal combination of conditions and equipment to produce practical fusion power in 2032. The company has been busily producing power plants since that time, at its manufacturing facility in Yukon Territory. Although it can assemble large municipal power plants at customer-specified sites, its most popular product is a self-contained unit that can be shipped on a modified commercial version of a C-18 transport aircraft, and installed by local labor with supervision provided by a company engineer. The unit, weighing 200,000 pounds, includes a 17-foot diameter sphere, its 80-foot-long cooling "barn", and a support "shed". The system is shipped pre-assembled, and generates 10 MW, appropriate for non-industrial communities of about 5000 people. Fusion Founders has received several solicitations to develop a version of this unit that could be launched into space, but feels that it has achieved the theoretical limit of smallness for a fusion reactor, and cooling is not practical in space.

Garden-A-Go-Go manufactures portable hydroponic and aeroponic eco-systems at Alexandriat for sustaining long-duration spaceship crews. The modules are modified CASSSCs that attach to the exterior of a ship, over an airlock that would normally go to vacuum; new inter-orbit spaceships are designed with appropriate interfaces. Sizes are available for crews of five ($3 million), eight ($4 million), or twelve ($5 million), and special orders are cheerfully filled. Use of a Garden-A-Go-Go system requires that two crewmembers be trained to work the farm for one hour per day on average, mostly to harvest food for each day's meals, cull dead matter, and check for pests and disease. Customers select either rabbit-based or chicken-based systems, which deliver grains, vegetables, fruit, and meat (or meat and eggs). The systems do require bi-annual maintenance to replenish water and nutrients, introduce non-inbred animals, and replace plant species that have died off. Specialised installations for more than 1000 people can be ordered for $75,000 per person.

Hard Roll accepts ores from lunar mining operations, refines the metals, and produces rolled sheets, extruded beams, and custom shaped cast parts. The processes require approximately 10 GWh of electric power per ton of aluminum or titanium, and 2 GWh per ton for other metals.

Holey Moley adapted designs of excavation equipment used on Earth, for use in 1/6 g on the lunar surface. It has created mining equipment, trench-diggers, backhoes, dirt-movers, graders, drills, and tunnelers, and will create new machines on request. Some types of applications require more than one design solution, depending on whether local conditions enable bracing the equipment to compensate for lack of gravity. The company founder says “rocks on the Moon are just as hard as rocks on Earth, but my machines don’t have the same weight to punch through them”.

Large Print adapted capability for 3D printing of large parts to the lunar environment. The company Hard Roll provides metal feedstock for printing parts going into spacecraft, construction equipment, and land vehicles. Large Print is experimenting with feedstocks and equipment to replicate “whole house machine” printing done with concrete on Earth.

Litigation Limiters is a law firm that created a niche market which virtually eliminates conflict-of- interest suits for its clients, who usually are companies competing for the same contracts but in need of each others' products and/or services. Litigation Limiters arranges its own contracts between providers of products and services, and customers, then serves as a go-between to supply the products and services to the customers. The company has such agreements with all of the world's diversified corporations that have significant product lines applicable to space development. Litigation Limiters charges a 2% fee on product or service value.

Lossless Airlocks has developed and sells airlocks that operate with almost no loss of atmosphere for each opening to space. Airlocks come in several sizes, including a single-person unit, a personnel transfer system that can simultaneously accommodate three people in adjacent chambers, and small versions for exposing experiments to vacuum without requiring an astronaut to go EVA. Units that can accommodate more people and CASSSCs are too big to launch, so specialised airlocks for lunar applications are built at Alaskol, and airlocks for orbital use are built at Bellevistat.

Mirror Image makes mirrors from lunar materials that are used to reflect sunlight while allowing radiation to pass through. The standard size is 13.5 feet (4.11 m) by 30 feet (9.14 m); up to 175 panels can be shipped in a specially modified CASSSC.

Nano Solutions was established at Alexandriat to commercialise production and marketing of nanobots after techniques were developed to grow them in zero g and vacuum. The microscopic robots perform tasks at the molecular level--primarily modifying molecules to form an airtight seal on interior surfaces, fusing coatings on surfaces, and separating elements mixed in metallic asteroids Programmed nanobots sell by the ounce at roughly ten times the cost of platinum; when delivered they resemble a fine powder the customer applies as a thin layer to the working surface. Service life is one to five Earth years, depending on operating environment and application.

OrbitLink Communications was established when the Alexandriat Space Settlement was under construction, to augment traditional communications channels. It subsequently developed standard equipment adaptable to any habitable space installation. The company has made arrangements to place one of its antennas and dedicated fiber optics links on every Foundation Society settlement.

Remotely Local Products is a spinoff of a Vulture Aviation team that commercialised manufacture of common household and office items from lunar materials. The company slogan is “give us carbon and silicon, and we’ll give you home”.

Seals-It-All makes paints and coatings from lunar materials that provide air-tight surfaces on rock, SuperAdobe, and other solid but porous surfaces. Application is done with standard paintbrushes that can be manipulated by robots, and the surface requires two Earth days to dry before it is capable of retaining air at Earth sea level pressure.

Soil Solutions converts lunar and asteroidal dirt to non-abrasive soil for agriculture and landscaping. Products are delivered in CASSSCs, which must be unloaded in a thermally benign and pressurised environment to preserve the biota in the soil.

SpaceTrans, Inc. started as a business plan written for a college class project by an ambitious self-styled entrepreneur who idolises the founder of Federal Express. The company acquired financing to build vehicles in space that can provide regular but unscheduled transportation services between locations in Earth orbit, including space stations, major commercial sites, and future settlements. Although primarily intended as a service for passengers and their luggage, the company can haul some cargo either in small packages that fit in the passenger compartments, or secured to the exterior of each vehicle. Rates average $20,000 per person per day of travel, and $100 per pound of cargo per day of travel.

Stuff of Life has developed processes to make air and water from lunar materials. The company founder says "Don't ask where we get Nitrogen." Air and water are shipped in sealed CASSSCs; air can be liquefied to reduce volume for shipping. A large production facility at Alaskol is the primary supplier of air and water as the human economy expands in the solar system.

Toss It To Me has developed processes for recycling trash and garbage from lunar and space habitations. What it receives is diverse and variable; the company President says "what we do is almost like alchemy, and most of what we recover to sell is byproducts". An especially valuable byproduct is methane from rotting garbage in landfills. Current processes manage to repurpose about 50% of input; a goal is to send no more than 10% to landfill. Each customer must allocate an interior area equivalent to 1% of the residential community's land area for a building where conversion processes occur, a similar area outside the settlement for an unpressurised structure, and a third area as a landfill.

Waste Products has developed toilets and sewage handling systems that work in reduced gravity, and convert human waste to recycled water, excellent fertiliser rich in phosphorus, and a source of carbon. The systems do require that users decide before each sitting whether they will do "#1" or "#2". The company works with developers of new lunar habitations to design and install sewer systems; it requires uninhibited access to a building site for 100 homes for one month after the site is graded and prepared for construction.

ZAP! Industries is the leading supplier of wire harnesses for distribution of electrical power, and fibre optics systems for electronic signals on spacecraft. The company operates a system for zero- g manufacturing of solar cells from materials available in silicate asteroids. ZAP! sells each of these units for $40 million, not including transportation to deposit it on an appropriate asteroid, where it produces 1 x 2 foot solar panels at the rate of 1,000 per day, each of which is capable of generating 38 watts of power in Earth orbit and weighs 2 pounds, at a cost of $80 per kW (not including transportation to the user site).

Zero-G Mobility provides standard rail systems enabling access of vehicles and robots on exteriors of orbital structures in zero g. The rails have a quick-attach / quick-release capture system that keeps objects attached, with capabiltiy to easily transition between different rails.