

Massless Exploration – Humans as a Solar System Species

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ABSTRACT

A vision for exploration of the solar system in an earth independent manner is presented taking into account key drivers, challenges and future technological advances. This work was in response to requirements set by the NASA Advanced Exploration Systems (AES) Office. Planetary targets, key assumptions and approaches to utilizing non-terrestrial resources are presented. The mission was divided into four sprints. The first sprint aims at a settlement on Earth's moon. The second sprint aims at establishing a Lagrangian point station near the moon. The third sprint leads to the colonization of Mars and its moons. The fourth and final sprint investigated the exploration of Callisto, a moon of Jupiter. Bio-inspired approaches to technology and processes were considered to ensure that the in-space habitats are Earth like. The conclusion based on exploring the four sprints is that it is feasible to colonize the solar system without relying on earth but this relies on critical technology development and investments in emerging areas.

INTRODUCTION

A NASA Glenn team conducted a preliminary survey of technologies and ideas for Massless Exploration. Massless Exploration emphasized the importance of In-Situ Resource Utilization (ISRU): using space resources to augment or enable new in-space capabilities and allow new missions of exploration. Four different sprints were used to focus the discussions. A wide range of ideas were generated, and a set of roadmaps for implementing the technologies were assembled.

The Advanced Exploration Systems (AES) Division sought input on the concept of Massless Exploration (ME) to support its long range planning efforts. Massless Exploration is related to In-Situ Resource Utilization (ISRU), the use of space resources to enable improved mission capabilities or, in the far future, allow independence from Earth. NASA Glenn was asked to participate in these exploratory activities that were initiated by a statement of work (SOW) outlining the AES requirements. A cross-functional, multi-

discipline team worked over the course of several weeks on various activities to generate the requested deliverables. The team used a scenario approach to creatively explore possible futures for deep space exploration and settlement. The team considered a range of planetary targets to shape and guide discussion of options and alternatives. The target areas were:

- a) the Earth, Moon system,
- b) a Lagrangian Hub at L2,
- c) the Mars, Phobos, Deimos system and
- d) the Jupiter, Callisto system.

THE APPROACH AND SPRINT SUMMARIES

An in-space scenario was used to frame discussions and creative thinking. The scenario provided four planetary targets (Earth-Moon, Lagrangian Hub, Mars, and Callisto) for the team to explore the feasibility of incorporating massless exploration of space over a period of fifty years.

The work was planned in terms of sprints and working sessions: there were 4 sprints initially, then a series of weekly working sessions to formalize and package the final documents and deliverables. A 'sprint' was defined as 2 – 2 hour sessions per week – one sprint for each target location. The first session was typically devoted to blue-sky discussions guided by a series of questions, the second session was used to fill information gaps, discuss technical literature supporting key ideas and finessing recorded results.

The team concerned itself with the minimal elements needed for survival with little to no need for return or be resupplied from Earth. Recurrent discussion themes included life support systems, medicine, artificial gravity, vehicles, habitats, power, propulsion, communications, redundant and protective systems, space suits and psychological well-being.

Key assumptions

Each sprint opened with a brief destination description to orient and frame the discussion. A list of key assumptions was then generated to establish boundaries to consider when exploring future options. The assumptions were:

- No cataclysmic events (major terror attacks, asteroids hitting earth, nuclear war between nations) precipitated the need to explore, travel and colonize space.
- US economic and political structures are intact and function in accordance to today's norms.
- Significant advancement in creating a space faring nation requires a complete breakthrough in thinking about sharing and pooling resources – this will require

unprecedented collaboration across international boundaries– and the acceleration of technology development and breakthroughs.

- Current trends in technology and artificial intelligence will likely progress and enable developments discussed in this exercise.
- Humans will likely be enhanced while on Earth to prepare for future long-duration space missions (i.e., pre-mission drug therapy to help overcome bone density loss, muscle mass loss.)
- Advancements in technology and medicine will gradually increase life expectancy for space explorers and settlers.
- Gene manipulation and therapies will evolve providing cures for certain cancers, viruses and diseases. Advancements in these technologies will contribute to the increase in life expectancy.
- Human life expectancy can increase by 10% due to medical and technological advances.
- There will be at least three space-faring markets to be served by the space economy – homesteaders (settlers), passengers, and mission crew. The homesteaders will likely travel to the Moon to live, explore and never return to Earth. Space passengers will travel to space destinations for specific purposes (leisure, medical, service, construction, food production, industrial production) and then return to Earth. Mission crews will likely travel to space destinations on behalf of government consortiums to complete reconnaissance and exploratory missions.

Key drivers

Key drivers for establishing a sustainable presence in space include:

- Provide economic and lifestyle benefit to people on Earth
- Enable space tourism and encourage homesteading – leading to future colonization
- Gain scientific knowledge that is of benefit to humanity
- Answer the big questions – to better understand the nature of the Universe
- Enable the human expansion into the Solar System
- Bolster confidence for developing a space faring citizenry
- Ensure people can work, learn and live safely beyond Earth in sustainable ways
- Aid in cataclysmic disaster recovery (i.e., Earth collision with an asteroid or comet - space colonies can assist in disaster recovery)
- Expand the human experience.

Sprint results

The following Sprint summaries provide a high-level overview of how massless exploration could conceivably evolve over time. Initially, space settlement is highly Earth-reliant but the longer settlers and explorers remain in space, the more their survival is decoupled from Earth's resources. This is due, in large part, to acclimating behaviors required to live 'off the land'- excavate, cultivate and fabricate local lunar resources in sustainable ways. The Appendices provide the sprint summaries and the key industry partners.

Sprint 1 was focused on a base and ultimately a settlement on Earth's moon. The Moon is nearby Earth and is rich with resources. The Moon's proximity to Earth makes it an excellent place for practicing for future far flung space operations. Water resources will likely be tapped from reservoirs at the lunar poles. Permanently shadowed craters (PSC) with water ice have been discovered on Mercury, and there is also evidence that such water deposits are on the Moon. From that water ice, oxygen and hydrogen propellants for ascent and descent to the Moon would be produced. Also, hydrogen for electric propulsion systems would be shipped from the Moon's surface to an orbiting space vehicle or propellant storage depot.

Factories and other devices for detecting, capturing, purifying, processing, transporting, and using the lunar materials will be crucial for the future Sprints to the Earth-Moon Lagrangian points, Mars, and Callisto.

As the base becomes more capable of supporting larger and larger crews, many people will likely begin "settling the land" and remaining on the Moon. Such settlements will require large capacities to produce oxygen, food and water for long term occupation and creating a comfortable lifestyle for families and other large groups of people.

Synthetic biology techniques will pave the way for growing fruits, legumes and vegetables that can be further cultivated to improve flavor and texture. Fisheries will also be cultivated as an additional protein source. 3D printed foods will also be available. Humans will be working alongside intelligent robots. Robots will literally be doing most of the 'heavy lifting' in space building and construction. They will be employed to build structures, assemble space vehicles, terraform regolith and perform a host of menial tasks. These robots could mimic biological evolution such that they not only build other robots, but can also optimize itself in subsequent generations. Synthetic biology will enable the production of medicines using herbs and plants cultivated in situ. While this will enable many medicines to be available on demand, explorers and settlers will likely be sent to Earth for treatment and recovery of major illness and disease.

In **Sprint 2**, a Lagrangian Point station in the Earth-Moon system was assessed. The Lagrangian points are gravitationally stable points (in a general sense) that can be used for storing space vehicle cryogenic propellants and their related storage components away from a thermally hot location (such as a planetary surface). Also, the escaping the Lagrangian point is easier than escaping from a low orbit about the Moon, thereby reducing the propellant needed for interplanetary flights. This location can be attractive staging and

assembly point as well as a jumping off point for future space vehicles travelling to the planets.

Advances in synthetic biology and botany will spawn flavorful and nutritious foods that are easier to digest and yield a lower production of human waste. More varieties of food will be grown as hydroponic technology will be scaled to meet the growing demand. While more medicinal herbs will be cultivated for drug technology in space, travelers will take advantage of customized doping programs matched to individual DNA as a preventative measure for illnesses, bone and muscle loss. Gene manipulation and therapies will also evolve - providing cures for certain cancers, viruses and diseases.

The key medical focus will be on solving the problem of cancer caused by Galactic Cosmic Radiation (GCR). This will require having the ability to cure cancer when it appears or employing preventative measures such as prophylactic drugs, shielding, fast propulsion and short stays in radiation environments (this would also encompass sending explorers back to Earth. Advances in virtual technology will enable explorers to be fitted with augmented reality helmets, glasses and electronic devices to aid in task performance. Even augmented reality (AR) devices will evolve over time – from providing detailed data to interactive query and learning systems using virtual reality. Space travelers will be able to learn in space and avoid the need to return to Earth for medical attention or even equipment repairs.

Sprint 3 investigated Mars, its moons, and its orbital vicinity. Water has been discovered beneath the surface, and that precious resource can be used to sustain life and for rocket propellants. On Mars, oxygen and hydrogen propellants for ascent and descent to the moons would be produced. Also, hydrogen for electric propulsion systems would be shipped from the moon's surface to an orbiting space vehicle or propellant storage depot.

Food products will continue to improve and diversify. Super-foods densely packed with phytochemicals and anti-oxidants that bolster the ability to prevent certain cancers, illness and disease will be popular in space and on Earth. Closed-loop, ecological life systems (food pods) will be ever present and enable all waste to be recycled. Medicines will continue to advance as more is understood about the effects of space on the development of the human body. More medical processing facilities will be built to process medicinal herbs and plants in situ.

Habitats will become more elaborate and will be pre-assembled, on demand, using autonomous robots. All utilities will be 'built into' the habitat so no special skill is needed for tie-ins and hook ups. Some short term habitats may be inflatable and shielded by a combination of regolith and water. Long-term facilities will likely be large, multi-level underground domed communities. They will incorporate advanced technology and communications systems – telepresence and holograms will be used to avoid exposure to radiation. Games and entertainment will rely upon these technologies as more emphasis will be placed on building and maintaining connections within the community without physically 'being there'.

With the development of more resource processing facilities, more vehicles can be made using in situ materials. Simple vehicle parts and replacement parts will be created using stock sourced from waste and lunar resources. There will be some reliance on Earth for

complex electronics. Resources for vehicle patching will be pre-positioned on near Earth asteroids (or a satellite such as Deimos). These resources will enable on-demand printing of parts and patching materials in the event of an emergency repair to a vehicle. Advanced materials and fusing techniques (using lasers and scanners) will enable quick patches to space ships. Augmented reality devices will provide repair instructions so travelers can successfully repair the vehicle.

For **Sprint 4**, the destination was Callisto, a moon of Jupiter. Callisto is in an orbit that is located near the outermost part of the powerful magnetic fields of Jupiter. These magnetic fields trap high energy particles from the Sun and the other Jovian moon and create dangerous radiation fields about Jupiter.

Callisto is essentially an airless body with a very tenuous atmosphere, it has a low gravity, and it is extremely cold. However, this moon is important because of its ice-rock composition. The water ices can be used for propellants and to help sustain life. At Callisto, oxygen and hydrogen propellants for ascent and descent to the moon would be produced. Also, hydrogen for electric propulsion systems would be shipped from the moon's surface to an orbiting space vehicle or propellant storage depot.

Additional materials from the moon can be used for constructing living quarters, storage areas, and human shelters from many forms of radiation. If needed, additional space vehicle replacement components can also be constructed.

With the exception of specialty items, all food is sourced in situ. Foods will be so similar to those enjoyed on Earth that it is quite conceivable that space grown food will be sent back to Earth. Earth will enjoy many advantages of new 'super' drugs developed in space that will cure predictable diseases (such as diabetic related blindness) and thwart a variety of persistent illnesses.

Technology transfer will undoubtedly boost public confidence in space settlement. In vivo nanotechnology will revolutionize medical procedures and the way medicine is administered worldwide. The effects of long duration travel in space will dramatically advance our understanding of the aging process. While new cancers will likely develop, many types of cancer will become obsolete due to advancements in detection and treatment. Gene manipulation will likely play a key role in thwarting some cancers.

Rovers and hovering vehicles (from advanced materials) will likely be sent from Earth and assembled in space. It is possible that these vehicles are manufactured on the Moon or a near Earth asteroid. Mobile submersible exploration vehicles will be assembled in space. All operations will be conducted in cryogenic temperatures. This will require advantaged materials and composites suitable for super-cold environments. Encapsulated portable heat sources will be used to keep equipment from freezing.

Mission requirements will drive type of propulsion system technology and propellant. Available resources will drive the type of propellant system and propellant to use. Nuclear propulsion systems will likely be used - many components made and assembled using local resources, reactors will likely be sourced from Earth. Rocket propelled hovering vehicles will be powered by oxygen and hydrogen from native ice.

CONCLUSIONS

Massless exploration, or the use of the vast resources available beyond Earth, will allow humanity to more effectively explore space and flourish in many regions beyond Earth. Human exploration of the solar system is the next step beyond our current set of robotic exploration and prospecting missions. We have used the extensive capabilities of robots to gather data on the mineralogical and chemical composition of the other planets and their gaseous atmospheres. Using this data, we can formulate plans to use these minerals and gases to sustain human life and bolster our exploration plans.

Massless exploration is possible because of the detection and accessibility of plentiful resources throughout the solar system. The capabilities of remote sensing from spacecraft flybys or those in orbit about other solar system bodies have detected almost all of the raw materials for exploration, human bases, human colonization, and self-sustaining facilities. Structures can be made from the regolith (rock and dust) or from the metals in the regolith. The regolith will be an effective shield for many aspects of natural space radiation. Propellants will be made from caches of water in permanently shadowed craters on the Moon, from the polar regions of Mars, or the icy surfaces of the outer planet moons. These propellants would supply both chemical and electric propulsion space vehicles. Extensive electrical power would be available from solar cells produced from the regolith materials: silicon, oxygen, and rare metals.

Massless exploration allows humanity to extend itself beyond Earth. This is important as human life, if limited to one place in the solar system, will ultimately perish. Natural disasters such as a supervolcano eruption or the impact of a large asteroid could potentially severely damage or end human civilization. As we have seen from past impact, 65 million years ago, a large asteroid impacted the Earth in the Yucatan Peninsula and destroyed the planet's ability to support all of the higher life forms. Dust was thrown up into the atmosphere on a planet-wide scale, blotting out the sunlight and therefore all of the plant life failed. Without food, the higher forms of animal life perished.

With human life in many parts of the solar system, such a catastrophe would be mitigated. With a complex network of asteroid detection telescopes, such bodies would be found and deflected with advanced propulsion systems. In any case, if such deflection were impossible, the Earth could be ultimately repopulated from the other cradles of humanity in other parts of the solar system.

Medical technologies may blossom from the new discoveries made in space. Research on the International Space Station (ISS) has shown the deleterious effect of microgravity on bone and muscle mass. Additionally, we have discovered that the fluid shift into the upper part of the human body causes intercranial pressure increases, affecting and in some case damaging human eyesight. Solutions to these and other issues may come from extended exploration and homesteading in space. New pharmaceutical research away from Earth will no doubt produce new countermeasures against many human diseases.

A general conclusion of the ME studies were that human life can be extended into many places in the solar system. Overall, the materials to allow for construction of shelters, building, laboratories, greenhouses, landing pads, and space vehicles all exist at many solar system destinations: the Earth's Moon, Mars, the asteroids, and the moons of the outer planets. Extending the human reach will provide all of humanity with a new and refreshing perspective on the human condition and allow us fulfill our destiny in the solar system and finally the stars.

The key findings from the Sprint scenarios were focused on the resources of water, oxygen, hydrogen, metals, and trace elements available throughout the solar system. From these basic materials, all of the possibilities of human exploration and colonization are clearly achievable. Extensive exploration of the Moon will provide humanity with new techniques in engineering, physics, chemistry, medicine and art as the human bases and colonies grow and seek all of the knowledge and inspiration that the Moon holds.

At the Lagrangian Point stations, new destinations and new perspectives on space vehicle construction will lead to numerous innovations. At Mars and its moon, vast resources of water and minerals will lead to permanent settlements and we will glean unimaginable knowledge of the geological and atmospheric processes that shapes that planet. At Jupiter, the moon Callisto will be an excellent observation point for the entire Jupiter system, allowing humanity a waypoint to Jupiter's many moons and also to the other outer planets, Pluto, and the Kuiper Belt.

The research for ME has been on-going for decades, since the 1960's. Several of the first lunar exploration studies investigated creating oxygen from simulated lunar rocks, even before we returned rock samples from the Moon. Success with these experiments and the ultimate detailed studies of actual lunar regolith samples have revealed nearly all of the materials for sustaining human life are "out there." The inquisitiveness of humanity is nearly boundless. Our planet is so small compared to the rest of the solar system and certainly the rest of the galaxy. Yet, we as humans have the fantastic capacity to dream impossible things and make those dreams a reality. Using the nearly infinite resources of outer space can unleash all of human creativity and make all of our lives more fulfilling and hopeful.

Massless Exploration (ME) has powerful implications for the human and robotic exploration and space settlement. With ME, we can allow human life to flourish in the solar system.

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Appendices: Sprint summaries and key industry partners


Sprint Summary - Systems - 2 of 3 Legend | Green cells indicate - Earth dependent

Target	Earth - Moon (2025)	Earth-Moon Lagrangian Hub (2030 - 2045)	Hub (L2) Near Earth Asteroid Mars (2030 - 2045)	Hub (L2) Callisto (2060 - 2065)
Protective Systems	Use regolith for shielding	Magnetic field generating devices to protect against solar flares	Infrastructures to detect, assess and deflect asteroids to prevent disasters on Earth and other human colonies in the solar system	Portable magnetic field generating devices to protect against solar flares
Space Suits	Made from thin, light weight Next generation space suits incorporating the technology of thin constricting, unpressurized spacesuits (see Dana Newman's work)	Protective and smart textiles more embedded and integrated into human diagnostic and health monitoring devices; feedback via alert systems, dispense drugs, first responder capability	Using in situ resources (propellants and propulsion structures) from the moon or the asteroid to deflect the asteroids	Thin materials, pressurization may not be necessary - with adequate thermal and radiation protection

Sprint Summary - Systems - 1 of 3 Legend | Green cells indicate - Earth dependent

Target	Earth - Moon (2025)	Earth-Moon Lagrangian Hub (2030 - 2045)	Hub (L2) Near Earth Asteroid Mars (2030 - 2045)	Hub (L2) Callisto (2060 - 2065)	
Redundant Systems	Cross-trained personnel Two fault tolerant infrastructure (emergency back up systems) Spacecraft system components that can be repurposed in multiple ways	Lunar-derived propellants pre-positioned at Hub for travel to Mars Rapid production of space solar power to avert an impending energy crisis on Earth	Separate missions so that each spacecraft has emergency rescue capability for the crew of the other Rapid production of space solar power to avert an impending energy crisis on Earth	Mars moons-derived propellants for Mars ascent-descent and travel to Callisto	Dissimilar power systems enabled by local environment as backup to main nuclear power (e.g. native H ₂ O, fuel cells, electrochemical cells (see power critics))
Communications	Communication networks - high capacity communications systems Space Communication and Navigation (SCAN), (inter-planetary augmentation to the deep space network)	High data rate megabit/gigabit/terabit per second data rates for space traffic control systems Optical communication systems High power science instruments (high power IR radar)	High data rate megabit/gigabit/terabit per second data rates for space traffic control systems Optical communication systems High power science instruments (high power IR radar)	Utilizing quantum physics (quantum entanglement) for breakthrough/disruptive technological advances	

Sprint Summary - Systems - 3 of 3

Target	Earth - Moon (2025)	Earth-Moon Lagrangian Hub (2030 - 2045)	Hub (L2) Near Earth Asteroid Mars (2030 - 2045)	Hub (L2) Callisto (2060 - 2065)
Artificial Gravity		Centrifuge/rotating crew quarters to minimize the effects of low gravity	Artificial gravity using rotating tethers on habitat and space vehicle - explorers have exposure to Earth normal/Mars normal gravity	

Sprint Summary - Energy/Fuel
Legend | Green cells indicate - Earth dependent

Target	Earth - Moon (2025)	Earth-Moon Lagrangian Hub (2030 - 2045)	Hub (L2) Near Earth Asteroid Mars (2030 - 2045)	Hub (L2) Callisto (2060 - 2065)
Power Energy	Solar - Earth based and solar cells created with Lunar materials	Employing technologies that convert radiation into energy	Nuclear power plants for high capacity manufacturing	Alternative energy possibilities in the Jupiter system (fusion, beamed power, electro dynamic tethers, advanced fusion)
	Fuel cells using oxygen and hydrogen	Power grids	In situ manufacturing of solar arrays or power at established target locations	
Propellants	Thermal energy		Advanced energy storage using in situ materials	
	Multi-functional power source - power transmission among vehicles			
	Nuclear - radioisotope thermoelectric generators (heat sources) and reactors			
	Oxygen from regolith for chemical propulsion	Nuclear	Methane for chemical ascent/descent	
	Hydrogen and oxygen from water ice for chemical propulsion			
	Hydrogen for electric propulsion, Nuclear Thermal Propulsion (NTP)			
	Argon (traces in regolith) for electric propulsion			

Sprint Summary - Vehicles
Legend | Light Green cells indicate - Partially Earth dependent | Green cells indicate - Earth dependent

Target	Earth - Moon (2025)	Earth-Moon Lagrangian Hub (2030 - 2045)	Hub (L2) Near Earth Asteroid Mars (2030 - 2045)	Hub (L2) Callisto (2060 - 2065)
General	Earth-to-Orbit - conventional launch vehicles, evolving into advanced low-cost launch vehicles	Earth-to-Orbit - conventional launch vehicles, evolving into advanced low-cost launch vehicles. These vehicles use only Earth derived propellants and not lunar derived materials.	Precision landing technologies	Rocket propelled hovering vehicle powered by the oxygen and hydrogen from the native ice
		Deep-Space Cargo Transfer Vehicles - Earth orbit to the lunar Lagrangian supply depot and also from the supply depot to other destinations. Transit times can be long.		Mobile robotic, submersible exploration vehicles
Vehicle Health & Reliability	Vehicle maintenance (lifetime flights)	Deep-Space Crew Vehicles - from Earth orbit to the Lagrange point supply depot and onward on exploration missions. Transit time is now a consideration, or shielding and artificial gravity, life support and habitat modules may be required.		
	Vehicle condition monitoring for safety/abort scenarios	Lunar Landers/Ascent Vehicles - these go from the lunar Lagrangian supply depot to and from the lunar surface. Low complexity vehicle parts will be made from lunar derived materials.	Capability to make specific replacement components in situ	

Key Industry Partners - 1 of 4

The concept of massless exploration can be a unifying theme for rallying the attention and support of the public. Massless exploration principles strongly appeals to common sensibilities like our need to find sustainable ways for survival, altruism and using our national pride for good to name just a few.

The Glenn Research Center Massless Exploration Focus Group has identified a list of entities that will have a vested interest in collaborating with government-led consortiums on massless exploration and settlement of space.

Industry/Co.	Established Earth	Established Space	Prospective Space	The Hook
Aerospace	●	●		Build and operate transport vehicles
Auto	●	●		Mfg. lunar rovers – cont. evolution of rover technology
Food	●		●	We pay them to keep explorers and settlers healthy
Tourism and Entertainment	●		●	Building hotels, tourist sites for short term and long term lodging New market - To provide a social outlet to maintain mental health; to provide gaming on Earth to teach future habitants/explorers behaviors needed to thrive in space
Health	●	●		We pay them to keep explorers and settlers healthy They learn about biological issues which may have terrestrial intellectual property (i.e., calcium metabolism) New market space - pre-Mission drugs for preventative doping regiments, herb farms to develop medicines, drug processing facility

Key Industry Partners - 2 of 4

Legend

Established on Earth - has an established business on earth with products that could be transferred

Established industry in space - has an established business in space with products that could be expanded

Prospective in space - future opportunity that is not yet established

Industry/Co.	Established Earth	Established Space	Prospective Space	The Hook
Mining	●		●	Providing expertise for prospecting for materials for space; Harvest materials in space for use on earth
Materials and Mfg.	●		●	New market space – development of “super” materials and intelligent (smart) materials for use in space and Earth
Chemical Processing and Recycling	●		●	Learn about and implement green mfg on the moon that will have applications on Earth
Energy	●		●	Additional market space to provide energy in space Manage nuclear waste and energy production for use on the Moon Helium 3 industry (speculative)
Robotics	●	●		Autonomous terraforming; build facilities; process resources for fuel, learn how to streamline the building process
Maker Community			●	Participate in demonstrations and solving (through crowdsourcing) technical problems Will also be seeking ways to build and launch their own space assets – enabling cottage industries of surveyors and surveillance consultants

Key Industry Partners - 3 of 4

Legend

Established on Earth - has an established business on earth with products that could be transferred
 Established industry in space - has an established business in space with products that could be expanded
 Prospective in space - future opportunity that is not yet established

Industry/Co.	Established Earth	Established Space	Prospective Space	The Hook
Nanorobotics	●	●	●	Expands the market space for use in mfg. as well as medicine (in space and on Earth)
Clothing -Wearable Technologies	●	●	●	Mature market but always expanding and optimizing for greater performance. Human health monitoring, first response to injury, communication of injury, wearable computing/displays, augmented attachments (knowledge base). Prospecting to accommodate increased hazards and environmental challenges
Biomimetics	●	●		Paid to help space developers, builders, and growers and medical practitioners to optimize processes and to learn and apply adaptation principles quickly
Drone Technologies (robotics)	●	●	●	New market space enabling the transport of resources to meet demand; transport resources to Earth.
Computing	●	●	●	New market space - provide computing to operate equipment and facilities in space
Security	●		●	New market space - paid to keep international peace in space
Autonomous Mfg.	●	●	●	Little 3D robots building bigger. 3D robots prototypes sent to near earth asteroids and Mars
Camera/Sensor Technology	●	●	●	To establish a stake in the market for residential and commercial wearable device industry, robotic industry
Heavy Vehicle Industry	●		●	New market - paid to optimize and adapt vehicle construction process using materials found in space as well as recycled space ships

Key Industry Partners - 4 of 4

Legend

Established on Earth - has an established business on earth with products that could be transferred
 Established industry in space - has an established business in space with products that could be expanded
 Prospective in space - future opportunity that is not yet established

Industry/Co.	Established Earth	Established Space	Prospective Space	The Hook
Consortium of Power Companies	●		●	Paid to manage and provide expertise for power generation and distribution plants, maintain power grid knowledgebase, optimize power grids as demand/supply increases
Construction	●		●	Paid to build/erect structures and infrastructures throughout the solar system
Logistics Providers (Amazon)	●			Paid to warehouse and route on demand items to settlers and explorers
Biomimicry	●	●	●	Paid to optimize engineering design and processes by observing and applying nature's solutions to typical problems encountered in the space environment
Mental Health	●		●	New market (space medicine) - paid to ensure mental health of settlers and explorers
Pharma	●		●	Paid to provide and manufacture drugs using in situ herbs/plants
Recreation	●		●	Paid to provide recreational facilities and activities
Volunteers			●	Category of individuals who are not seeking compensation but an opportunity to serve their country and be part of the experience
Education	●		●	Paid to establish international space universities and colleges - concentrated on subjects/disciplines needed for space exploration and colonization
Space Agriculture (Botany)	●		●	New market (space agriculture) Paid to cultivate/grow herbs, spices and plants for use in enhancing foods and manufacturing medicines