CISLUNAR INDUSTRIES™ SPACE FOUNDRY™: RECYCLING SPACE DEBRIS INTO REFINED MATERIALS FOR IN-SPACE USE.

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Introduction: The cislunar economy is beginning to take shape and a new frontier is opening through the pursuit of valuable space resources. The space resources value chain will be at the core of this new ecosystem, supplying the materials needed to develop a self-sustaining economy in space. However, a critical link in this chain remains unoccupied. At present, insufficient attention has been given to the development of an industrial scale, in-space processing and refining capability for structural materials. Without this capability, all space mining efforts will fail to deliver materials in a format suitable for other activities, such as construction and spacecraft repair. The cislunar economy will remain dependent upon components delivered from Earth if this is not addressed. CisLunar Industries aims to solve this issue using an innovative and sustainable approach.

The Problem of Space Debris: The growing amount of space debris represents a significant societal challenge which is gaining increasing attention from governments and Space Agencies. There are approximately 7,500 tonnes of space debris in a wide range of Earth orbits. This debris presents a major risk for current and future missions. Most of the space debris mass is composed of intact objects, 80% of which are abandoned spacecraft and rocket bodies [1]. However, these objects also represent a large cache of reusable space-grade material.

Low Earth Orbit (LEO) and Geostationary Equatorial Orbit (GEO) are of particular interest for active debris removal and satellite servicing; in LEO, the Kessler syndrome threatens the usability of orbits for future constellations, and GEO contains more than 1,000 trackable debris objects larger than 1 meter that can act as a collision hazard for GEO satellites essential to modern infrastructure [2]. It is clear, therefore, that finding an appropriate method for removing debris where possible will be essential if frequent human interplanetary travel is to become a reality.

Current State of Space Debris Remediation: Numerous demonstrations of active and passive debris removal techniques are being, and have been, developed. RemoveDEBRIS is the first satellite on-orbit demonstration of active (harpoon, net, LIDAR) debris removal technology in Space [3]. It will also demonstrate passive (dragsail) technology on a microsatellite, having successfully demonstrated its application previously on a nanosatellite (InflateSail) [4]. Other concept demonstrators include CleanSpace-1, intending to use a collapsible net to capture one of their own 1U cubesats, and e.Deorbit, which is currently investigating technological links between debris remediation efforts and on-orbit servicing [5][6]. Other proposals also include the use of deboosting thrusters and high-power ground lasers [2].

Development of reusable Orbital Transfer Vehicles (OTVs) is also advancing rapidly, with several companies jumping onboard. Effective Space have developed the SPACE DRONE. Orbital ATK have developed their Mission Extension Vehicle (MEV). Space Systems Loral are developing their Robotic Servicing of Geosynchronous Satellites (RSGS) for GEO, and Restore-L for LEO. Airbus Defense and Space are also developing the Space Tug. Part of their servicing objectives will include removing derelict satellites from important orbital locations.

However, all of these methods are a pure cost and waste large amounts of space-grade materials already in orbit, focusing only on ways to remove debris, and expect remediation costs to be borne by governments or industry. **Using space debris as a resource however, transforms a major problem into a major opportunity.** CisLunar Industries™ intend to make this possible through the development of the Space Foundry™.

Vision: In its early stages, the Space Foundry™ will exploit the most readily available source of space materials near Earth, space debris. The Space Foundry™ will become the first on-orbit source provider of refined material for space manufacturing; for the orbital construction of large space stations, the orbital manufacture of satellite components (e.g. large reflectors, parts for satellite repair and retrofit), and the orbital assembly of reusable spacecraft, completely transforming the way materials and components for future spacecraft are sourced.

The Space Foundry™ will enable the fulfillment of CisLunar Industries™ long-term vision to position itself as one of the key enablers for on-orbit and interplanetary manufacturing, specifically as the first supplier of space processed material. By filling the gap existing between space miners and the space manufacturers, CisLunar Industries™ will become the primary processing company for the conversion of raw materials into usable resources for on-orbit and interplanetary manufacturing.

How It Will Work: *On-Orbit.* At the Space Foundry™, reusable space tugs will collect and deliver large debris items, such as spent rocket bodies and defunct satellites, to be processed and refined to customer specifications. The tugs will then deliver these finished materials to the desired location for customer use. By recycling space debris, CisLunar Industries™ will also be offering the first economically sustainable solution to address the space debris problem, not only generating an early revenue stream, but establishing a principle of long-term, sustainable use of the cislunar orbital environment.

The first Space Foundry™ will be located above GEO orbit, closest to its largest source of materials, the GEO graveyard orbit, and to its main initial customer, GEO satellite operators. Future versions of the Space Foundry™ will be deployed in other valuable orbits and locations in cislunar space, and will be tailored to the needs of space miners and their raw materials.

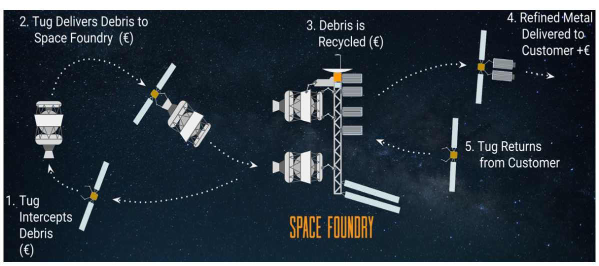

Figure 1: The Space Foundry™ mission architecture, from the collection of space debris to the delivery of processed materials to the customer.

On the Moon. The technology developed for the Space Foundry, along with the experience of manufacturing materials for in-space use, will enable CisLunar Industries™ to adapt the Space Foundry™ for use on celestial bodies. CisLunar Industries™ aims to be a main processing company for all interplanetary ventures in the future, focusing initially on the Moon. The technology developed for the Space Foundry's operation in the microgravity, vacuum, radiation and thermal environment of space will be concurrently adapted for application to the Lunar environment, serving as a key element in the establishment of the first extraterrestrial settlements.

Figure 2: CisLunar Industries Foundry completes the value chain of current lunar development efforts.

Conclusions: The industrialisation of cislunar space and the Moon is foundational to the establishment of a sustainable human presence beyond Earth. The ability to process and recycle structural materials in space is a critical piece of the infrastructure underpinning this endeavour. With the development and implementation of the Space Foundry™, CisLunar Industries™ aims to be the first company to fulfill this need. Starting with space debris will enable the development of the complete material processing capabilities needed for a mature cislunar economy, while also providing the first economically sustainable solution to the space debris problem.

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