In Space for Earth!

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Introduction

Following the first decade of assembly of the International Space Station (ISS) and the subsequent decade of research onboard the ISS National Lab, NASA is now moving boldly into a decade of results with the award of contracts supporting the commercial development of new and promising technologies for in-space manufacturing of advanced materials and products for use on Earth. With more than 22 years of continuous occupation, the ISS continues to demonstrate the benefits of microgravity not just for discovery but for the development of new commercial technologies and products that have the potential to strengthen national security and improve the quality of life on Earth for people everywhere. NASA's In Space Production Applications (InSPA) portfolio is unique in that it fosters utilization of the ISS for the benefit of the nation and humanity broadly, with no requirement for linkage to NASA's exploration goals.

The ISS remains a critical resource for NASA and its international partners to conduct research and prepare for exploration of the moon and Mars. NASA will continue to utilize the microgravity environment in LEO long after the retirement of the ISS to prepare astronauts, infrastructure, and equipment for long-duration missions beyond LEO as well as to advance basic and applied research and technology demonstrations for a wide range of U.S. interests. The traditional grant-funded research demand for LEO services has proven over many years to require substantial subsidies from NASA, including fully subsidized up mass, crew time, on-orbit accommodations, power, data, etc. NASA expects that this will continue for future commercial LEO Destinations (CLDs) that succeed the ISS. It is highly unlikely that future NASA budgets will be sufficient to pay all of the operating costs of a CLD. Therefore, if the goal of being "one of many customers" is to be realized, NASA must begin an effort that is sharply focused on enabling high-value capabilities such as in-space manufacturing during the remaining life of the ISS, using its subsidized resources. Successful ventures will support the breadth of the LEO services: they will require the scalability that a commercial platform can provide; their needs will support the growing U.S. crew and cargo transportation industry; and their presence on commercial platforms will provide the cost-sharing that will make NASA's research, technology development, and crew flight opportunities requirements much more likely to be affordable.

NASA's awards for Commercial LEO Destinations (CLDs) are a key piece of NASA's strategy for the development of an economy in LEO, aimed at enabling private space stations in LEO to provide these capabilities to NASA as a commercial service for the indefinite future. Another component of NASA's strategy, InSPA awards support innovative US businesses to enable sustainable economic development in LEO by stimulating in-space production of advanced materials and biomanufacturing products for commercial markets and public benefits on Earth.

The purpose of NASA's InSPA program is to provide funding and expertise to help the most promising U.S. innovators traverse the technology "Valley of Death" by proving out their concepts for space manufactured materials and products on ISS such that other public and private-sector investors can confidently join in during the commercialization phase. The ISS National Lab (NL) is an enabling partner and valuable resource for those seeking to develop and demonstrate advanced materials and emerging technologies for this purpose. Drawn from advances over the past decade on ISS coupled with new product needs in high technology and health sectors, innovative US companies in the InSPA portfolio are expected to advance solutions with high economic value by leveraging the capabilities and resources of microgravity through the ISS National Lab.

NASA expanded these efforts by reaching out to other Government Agencies (e.g., DoD, NIST, and NIH) for opportunities to collaborate on solutions that serve national interests or broad public benefits. NASA is not the customer for these technologies; NASA's exploration needs for technology demonstrations utilizing In Space Manufacturing are implemented and managed separately from InSPA. As of May 2023, NASA has provided seed money in excess of $60 million for more than a dozen technologies to enable innovative companies to mature their in-space manufacturing concepts and stimulate demand for future markets. The awards are a key element of NASA's goal to develop a robust economy in low-Earth orbit (LEO) where NASA will be one of many customers. In 2022, NASA selected eight additional proposals from U.S. businesses, institutions of higher learning, and other organizations totaling $21M to raise the technological readiness level of their manufacturing technologies and products, move them to market, and to propel U.S. industry toward developing a sustainable, scalable, and profitable non-NASA demand for products and services in LEO. These awards will lead to later phase awards for companies that successfully meet the pre-defined success criteria, ultimately leading to transition to commercial operations on a CLD of their choosing.

In spring of 2023, NASA released an update to Focus Area 1 - In Space Production Applications (InSPA) of the NASA Research Announcement for *Utilization of the International Space Station.* NASA will have two cycles annually that call for submissions in Tissue Engineering and Biomanufacturing as well as Advanced Materials and Manufacturing.

InSPA Portfolio Details

Mission

Ensuring U.S. leadership of in-space manufacturing in low-Earth orbit by enabling the use of the ISS NL to demonstrate the production of advanced materials and products for terrestrial markets.

Vision

A robust and sustainable space economy where a diverse portfolio of U.S. companies operate a broad array of commercially owned productions facilities alongside government and private astronauts living and training on the Commercial LEO Destinations that follow the ISS.

Strategic Goals

1. Serve national interests by developing in-space production applications for Earth that strengthen U.S. technological leadership, improve national security, and create high-quality jobs, and/or
2. Provide benefits to humanity by developing products in LEO that significantly improve the quality of life for people on Earth, and
3. Enable the development of a robust economy in LEO by stimulating scalable and sustainable non-NASA utilization of future commercial LEO destinations or orbital platforms.

Technologies of Interest

- **Advanced Materials and Manufacturing:** Semiconductors, Exotic Glasses and Fibers, Alloys, Ceramics, Industrial Crystals, Uniform Protein Crystals for Pharmaceuticals, etc.
- **Tissue Engineering and Biomanufacturing:** Cancer Therapies, Artificial Retinas, Stem Cell Reprogramming, Production and Differentiation for Personalized Medicine, Bioprinting of Organoids and Whole Organs, Nerve Regeneration Medical Devices, etc.

Award Phases

Awards are made thru a competitive selection process to proposals submitted to the NASA Research Announcement (NRA) for ISS Utilization. New technologies are selected and on-ramped based on their intrinsic merit, business approach and economic impact, management approach, and feasibility. As budget permits, concepts that successfully achieve Phase 1 exit criteria are invited to submit a proposal for the 2nd phase. Similarly, Phase 2 awards that achieve exit criteria may lead to a Phase 3 award, budget permitting. InSPA awards are typically flown under sponsorship of the ISS NL through collaboration with Center for the Advancement of Science in Space (CASIS). The 3 InSPA Phases are -

1. **Proof of Commercial Viability:** development and launch of a basic flight experiment for testing on the ISS to demonstrate scientific hypothesis, hardware performance and manufacturing process control. Anticipate 2-5 flight demos resulting in a product that is comparable to Earth-based state of the art.
2. **Proof of Production Quality:** development and launch of an advanced flight experiment and 3-5 additional ISS demos to achieve full production control, meeting specific performance targets that exceed Earth-based state of the art. Requesting 20% non-NASA investment to signal market interest and profit potential.

3. **Scaling and Logistics Demos:** Scaled Flight hardware production and in-flight operations on either ISS NL or a commercial LEO destination/platform to demonstrate commercial operations and end-to-end logistics model producing sufficient quantities to close the business case. Requesting 80% non-NASA investment.

InSPA Phase 1
Basic Flight Hardware Development and Demonstration in Microgravity for proof of Commercial Viability

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InSPA Phase 2
Advanced Flight Hardware Development and Demonstration in Microgravity for proof of Production Quality

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InSPA Phase 3
Scaled/Automated Production Facility Development and Operation in Commercial Microgravity Environment

Key Points

- **The business approach and economic impact matter -** Transportation costs, while declining, are still a major cost contributor, so the in-space product must be good enough to capture a sizable market or meet important national/public needs such that there is a long-term commercial viability
- **It takes practice -** microgravity can be beneficial and at the same time detrimental to the production of applications; we can accomplish amazing things, but unexpected challenges often arise, and failures are expected, so multiple iterations will be required.
- **We are in a race –** Other governments are investing heavily and will capture markets and compete for leadership of in-space production if we don't sustain a steady pipeline of new ideas and provide the assistance needed to achieve commercial readiness.

2022 Awards

- **Biomanufacturing of Drug-Delivery Medical Devices**

  Auxilium Biotechnologies, Inc. of San Diego, with support from Space Tango, is developing a drug-delivery medical device to more effectively treat people who have sustained traumatic peripheral nerve injury. Auxilium's NeuroSpan Bridge is a biomimetic nerve regeneration device that guides and accelerates nerve regeneration, eliminating the need for a patient to sacrifice a nerve in the leg to repair a nerve in the arm or face.

- **Expansion of Hematopoietic Stem Cells for Clinical Application**

  BioServe Space Technologies and The University of Colorado Boulder is developing a specialized bioreactor that will produce large populations of Hematopoietic Stem Cells (HSCs) to treat serious medical conditions including blood cancers, blood disorders, severe immune diseases, and certain autoimmune diseases, such as rheumatoid arthritis. The technology may enable safe and effective cell therapy transplantation, especially in children and younger adults, where long-term bone marrow cell repopulation is critical to the patient's lifetime health.

- **Establishing Production of Stem Cell Therapies**

  Cedars-Sinai Regenerative Medicine Institute, in Los Angeles, with support from Space Tango, will be the first to attempt the production of induced pluripotent stem cells (iPSCs) in microgravity, and demonstrate differentiation into heart, brain, and blood tissues in support of regenerative medicine uses on Earth.

- **Fabrication of *FlawlessGlass* in Microgravity**

  Flawless Photonics, Inc. of Los Altos Hills, California, with support from Visioneering Space, is developing specialized glass manufacturing hardware to process Heavy-Metal Fluoride Glasses (HMFG) in microgravity for terrestrial manufacturing of exotic optical fibers and other optics applications.

- **Volumetric Additive Manufacturing for Organ Production**

  Lawrence Livermore National Laboratory, located in Livermore, California, with support from Space Tango, is adapting their volumetric 3D bioprinting device for use in microgravity to demonstrate production of artificial cartilage tissue in space. The Volumetric Additive Manufacturing (VAM) technology is a revolutionary, ultra-rapid 3D printing method that solidifies a complete 3D structure from a photosensitive liquid resin in minutes.

- **Pharmaceutical In space Laboratory Bio-crystal Optimization Xperiment (PIL-BOX)**

  Techshot of Greenville, Indiana, a Redwire company, is developing the PIL-BOX system to produce small, uniform protein crystals as stable seed batches for pharmaceutical and institutional research customers seeking improvements/refinements in product purification, formulation and/or delivery.

- **Biomimetic Fabrication of Multifunctional DNA-inspired Nanomaterials**

  The University of Connecticut out of Storrs, Connecticut, in partnership with Eascra Biotech of Boston, Massachusetts and Axiom Space, will demonstrate biomimetic fabrication of multifunctional nanomaterials, to be used as effective, safe, and stable delivery vehicles for RNA therapeutics and vaccines, as well as first-in-kind injectable scaffolds for regenerative medicine.

- **Semimetal-Semiconductor Composite Bulk Crystals**

  United Semiconductors of Los Alamitos, California, with support from Techshot and Axiom Space, will produce semimetal-semiconductor composite bulk crystals commonly used in electromagnetic sensors for solving challenges in the energy, high performance computing and national security sectors.

- **Analyzing Global Competition and U.S. Leadership in Low-Earth Orbit Commercialization of In-Space Production Applications**

  In addition to the awards above, NASA made an award for a global market study of in-space production and manufacturing. The Institute for Defense Analyses (IDA), headquartered in Alexandria, Virginia, was tasked to help inform NASA's strategy and plans for enabling in-space manufacturing by studying global competition and the potential impact on U.S. leadership in key technology areas. IDA's Science and Technology Policy Institute (STPI) will analyzed the current and future capabilities, investments, and policies of space-faring nations, including China, related to on-orbit manufacturing of advanced materials and products to better inform the priorities for U.S. Government investments in InSPA towards developing a commercial low-Earth Orbit economy.

2020 Awards

- **Protein-Based Artificial Retinas**

  LambdaVision of Farmington, Connecticut, with support from Space Tango, has developed a system to manufacture protein-based artificial retinal implants, or artificial retinas to treat millions of patients suffering from retinal degenerative diseases, including retinitis pigmentosa (RP) and age-related macular degeneration (AMD), a leading cause of blindness for adults over 55 years old. The microgravity environment of space hinders convection and sedimentation in the manufacturing process, enabling more uniform layers, improved stability and higher quality thin films than can be produced on Earth. The team successfully achieved their target of 200 layers on multiple InSPA funded flights and have one additional flight remaining under another grant.

- **Stem Cell Production**

  Space Tango and its partner Cedars-Sinai investigated pilot-scale systems for the production in space of large batches of stem cells to be used in personalized medical treatment for a variety of diseases. The pilot-scale systems, built for the space station to serve as a basis for future commercial manufacturing systems, will incorporate regulatory strategies to support FDA clinical trial production of personalized medicine stem cell therapies on the space station.

- **Orbital Stem Cell Laboratory**

  Space Tango and its partners at UC San Diego's Sanford Consortium in La Jolla, California, are working to establish a new on-orbit biomedical sector for stem cell advancement, with a fully operational self-sustaining orbital laboratory anticipated by 2025. Stem cells differentiate into tissue specific progenitors that can be used in microgravity to better understand aging and immune dysfunction, providing an opportunity to accelerate advances in regenerative medicine and the development of potential new therapeutic approaches. The project completed the first of six Phase 1 ISS demonstrations after launch on SpX-24 and launched again on SpX-25 for its 2nd demonstration. NASA and Ax-1 crewmembers imaged bioreactors with fluorescent reporters and showed increase ADAR1 and tumor organoid proliferation. Cancer is the second leading cause of death and cancer cloning (self-renewal) induced by ADAR1, is a leading cause of resistance and relapse. ADAR1 induces hyper-proliferation of cancer in space compared with 1-G organoids. These NASA /ISSCOR experiments accelerated the development of Rebecsinib, an ADAR1 inhibitor, to prevent cancer recurrence. UC San Diego's Sanford Stem Cell Institute also launched the first "Astro-biotechnology Hub" in March 2023 thanks to a $150M gift from T. Denny Sanford to translate stem cell research in-space and on the ground, a major step in the development of an ecosystem for in-space production of stem cell therapies and countermeasures for cancer.

- **Universal Intelligent Glass Optics (UNIGLO)**

  Apsidal LLC. of Los Angeles, California, with support from Axiom Space, has developed the UNIGLO module to process various types of complex glasses in space from which optical fibers, fiber lasers, magnetic fibers, super-continuum sources, capillary optics and adiabatic tapers can be drawn. Market areas for products from this module include specialty fibers for low-loss and high bandwidth communications, high-power fiber-amplifiers, IR counter measures, supercontinuum sources, medical applications, remote sensing, X-ray optics, and laser processing. The UNIGLO module flew to ISS in 2022 and was operated over three sessions, returning in 2023.

- **Manufacturing of Semiconductors and Thin-film Integrated Coatings (MSTIC)-Semiconductor Manufacturing**

  Made In Space of Jacksonville, Florida, a Redwire company, is developing the MSTIC facility as an autonomous, high throughput manufacturing capability for production of high quality, lower cost semiconductor chips at a rapid rate. Market applications include semiconductor supply chains for telecommunications and energy industries.

Prior Awards

- **Industrial Crystallization Facility (ICF)**

  Made In Space has developed the ICF to provide proof-of-principle for diffusion-based crystallization methods to produce high-quality optical crystals in microgravity relevant for terrestrial use. Market applications include ultra-fast optical switches, optical waveguides, optical circuit lithography, high-efficiency ultraviolet light production, and terahertz wave sensors. The ICF flew to ISS in 2021 and was operated in two sessions over several weeks that year, returning in 2021.

- **Space Fibers**

  FOMS Inc of San Diego, California, has developed a facility-class instrument for fiber fabrication in the microgravity environment to improve the quality of specialty optical fibers with the promise of up to 100x reduction in insertion loss due to the suppression of crystallization and phase separation. Three generations of the Space Fibers machine have flown to ISS in support of multiple attempts to produce high-quality fiber from exotic glasses.

- **Fiber Optic Production (FOP)**

  Mercury Systems of Torrance, California, with support from NanoRacks, has developed a facility-class instrument for fiber fabrication in the microgravity environment to improve the quality of specialty optical fibers with the promise of up to two orders of magnitude reduction in insertion loss compared to traditional SiO_2 fibers due to the suppression of crystallization and sedimentation. in December 2020, Mercury successfully manufactured approximately 100m of ZBLAN optical fiber on the ISS with performance comparable to fiber made on Earth. Mercury conducted fiber draws with its 2^{nd} generation device on ISS after launch on SpX-25 in June of 2022, achieving a continuous draw of greater than 20m for a third time.

- **Turbine Ceramic Manufacturing Module (T-CMM)**

  Made in Space has developed the T-CMM to provide proof-of-principal for single-piece ceramic turbine blisk (blade + disk) manufacturing in microgravity for terrestrial use. The project focuses on advanced materials engineering ultimately leading to reductions in part mass, residual stress, and fatigue. Strength improvements of even 1-2 percent can yield years-to-decades of superior service life. Market applications include high-performance turbines, nuclear plants, or internal combustion engines. The T-CMM flew to ISS in 2020 and 2021 and conducted test prints that were returned to Earth in 2021.

- **Turbine Superalloy Casting Module (T-SCM)**

  Made in Space has developed the T-SCM to provide proof-of-principle for polycrystal superalloy part manufacturing in microgravity for terrestrial use. Market applications include turbine engines in industries such as aerospace and power generation. The T-SCM flew to ISS in 2021 and was installed but failed to operate.

- **Biofabrication Facility (BFF)**

Techshot has developed the BFF as a space-based 3D biomanufacturing platform capable of printing with live human cells without the addition of scaffolding or chemical bio-ink thickening agents, required for 3D printing with cells on Earth. BFF prints in space with low viscosity bio-inks that only contain cells and nutrients, which enable cells to remain healthy and mobile – a necessity for creating solid thick tissue. The 1st generation device was tested on the ISS in 2019 with partial success. A 2nd generation device was developed using private funding and flown to the ISS in 2022 for operations in 2023.

- **Industrial Cell Production Lab**

  Techshot has developed a ground prototype of a multi-functional laboratory to manufacture induced pluripotent stem cells (iPSCs) in orbit using adult cells then enabling the cells to develop into many other types of cells that can be used inside the BFF bioprinter and on Earth for regenerative medicine, especially cell therapies. Market applications include cell therapies for restorative health and autologous cell sourcing for bioprinting and vascular applications.