Reaching for the stars: biotechnological patents, challenges, and opportunities in outer space

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Humanity's exploration of outer space is not only a scientific endeavor in the physical sciences, but also a research area brimming with biotechnological innovations. Space exploration involves far more than aerospace engineering and astrodynamics — it involves biotechnology, too. And that biotechnology may play a key role in our ability to sustain human life in outer space.

While it has been over 50 years since American astronaut Neil Armstrong first walked on the Moon, NASA is preparing to return astronauts to the Moon next year with the Artemis III mission. *See* Mohon and Williams, "Artemis III: NASA's First Human Mission to the Lunar South Pole," NASA, Jan. 13, 2023 (available here: https://go.nasa.gov/3YG529Z).

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Meanwhile, recent discoveries from missions like *Inspiration4* in 2021 are shedding light on the biological impacts of space travel. *See* Jones, C.W., et al., "Molecular and physiological changes in the SpaceX Inspiration4 civilian crew," *Nature* (2024) (available here: https://go.nature.com/3X5n7gc). Biospecimens collected from the crew before, during, and after the mission revealed genetic changes, altered blood oxygen levels, and cognitive impacts. *Id.*

This research marks only the beginning of our understanding of outer space's effects on human health. Indeed, NASA's planned Artemis IV mission aims to see astronauts inhabit the lunar space station *Gateway*, paving the way for future missions to Mars. *See* Hambleton, K., and Williams, C.E., "NASA's Artemis IV: Building First Luna Space Station," NASA, Mar. 29, 2024. (available here: https://go.nasa.gov/4dr1Mnw).

As humanity looks towards someday venturing to Mars, biotechnological advancements will play a critical role in overcoming unique challenges posed by the extraterrestrial environment. For example, everyday processes here on Earth such as monitoring human health, cultivating crops, developing pharmaceuticals, preserving food, and ensuring sustainable resource management, must all be adapted for the harsh environment of outer space.

In this article, we highlight examples of biotech patents in space, and their role in sustaining human life in the cosmos.

Outer space agriculture

Growing certain types of plants under extreme conditions will be essential for life in outer space. But considering e.g., the absence of oxygen, gravity, light, nutrients, and the wide temperature variations, agricultural botany in outer space requires a different approach than here on Earth. Below are some examples of space agriculture patents.

Passive Nutrient Delivery System (PONDS) (U.S. 10,945,389): This technology employs a wicking material to passively link a water/nutrient reservoir to a growth cylinder where seeds are germinated and plants are produced.

According to the '389 patent, PONDS addresses limitations with existing International Space Station plant-production technology by providing consistent delivery of water/nutrients, improving oxygen transfer to plants, and allowing users to determine how much water is being applied. Long-duration missions into outer space will generally require a fresh food supply to supplement crew diets, which may be achieved by growing crops in microgravity environments.

Plant gene editing systems, methods, and compositions (U.S. 11,634,722): Inari Agriculture's '722 patent focuses on plants grown under hypoxic (low oxygen) conditions using gene-editing techniques, such as CRISPR. For example, the '722 patent discloses using gene-editing techniques to cultivate potatoes in low-oxygen environments, similar to what might be encountered in outer space. Such technology is reminiscent of Andy Weir's novel, "The Martian," in which astronaut Mark Watney cultivates potatoes on Mars to survive. *See* Weir, Andy. "The Martian." Crown Publishers, 2014,

Opportunity: By developing methods of cultivating plants in outer space, humanity can explore self-sustainable food production for long-duration missions and potentially establish extraterrestrial habitats. This would not only ensure the nutritional needs of astronauts but also contribute to the feasibility of prolonged space exploration missions.

Outer space pharmaceutical research

Due to biological changes that take place in the human body during space travel, certain aspects of drug development are tailored for space environments. Below are some examples.

Micro-Organ Device (U.S. 8,343,740 and U.S. 8,580,546): NASA's '740 and '546 patents are directed to a Micro-Organ Device (MOC). According to the '740 and '546 patents, the MOC serves as a drug-screening system with human or animal cell micro-organs to supplement and reduce animal studies.

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The MOC was originally designed to evaluate pharmaceuticals in zero-gravity, with an aim towards accelerating drug development and validation of countermeasures for humans in space, as well as evaluate biological stressors from space conditions. As the MOC patents explain, this technology was developed with minimal footprint and power requirements, micro-volumes of fluid and waste, and high throughput capacity, allowing for the research and development of new drugs and materials in space.

3D Mineralized Bone Constructs (U.S. 8,076,136 and U.S. 8,557,576): NASA and university researchers have developed a technique to grow 3D tissue constructs, similar to human bone, in a laboratory environment. According to the '136 and '576 patents, this technology facilitates studying bone physiology under the harsh conditions of outer space.

The patents state that "[t]he bone constructs … provide a low cost alternative in which to study the effects of microgravity, and of other space environment insults, such as radiation, on the process of bone formation/bone loss." Such technology may play a role in space medicine research.

Opportunity: Developing drugs and medical treatments tailored for space environments will help ensure the health and well-being of astronauts during prolonged missions. Moreover, insights gained from space-based drug development may also impact healthcare advances here on Earth, leading to breakthroughs in treating various diseases.

Food preservation/fermentation

Food preservation and nutrition technologies must also be tailored for the conditions of outer space. For example, a patent directed to the Surface Attached BioReactor (SABR) for Microbial Cell Cultivation (U.S. 10,072,239) discloses methods for enhancing food quality and nutrition in outer space environments.

The '239 patent discusses the cultivation of high-value food supplements, biofuel feedstock, and biological life support systems for humans in space using fermentation and CO_2-scrubbing. As the '239 patent explains, the International Space Station currently has no biological food generation capabilities onboard.

Thus, food must be uploaded from Earth at an approximate rate of 1,200 kg/year. The ability to produce and to preserve food in outer space will be key not only for supporting long-duration missions onboard the International Space Station, but also for ensuring the health and well-being of astronauts venturing far beyond the Moon's orbit.

Opportunity: Efficient food preservation techniques are important for extended space travel. Additionally, advancements in food preservation technology have the potential to revolutionize terrestrial food processing industries, leading to improved food safety and sustainability.

Cell culture biotechnology

Advancements in cell culture biotechnology may also address the complex challenges of space exploration and sustaining life on the Moon, Mars, and beyond.

One such technology in this field is the Miniature Bioreactor System for Cell Culture (US 9,023,642 B2): Scientists at the University of Houston developed a miniature bioreactor system for cell culturing and sampling.

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According to the '642 patent, the miniature bioreactor system is "mobile and has minimal reagent use for automated and unmanned operation in remote location such as space…." Specifically, researchers in space can study cell cultures and their response to stressors such as pharmaceuticals, hypoxia, and pathogens. This research has applications in pharmaceutical drug research and development tailored to be performed in outer space.

Opportunity: Microbial-based technologies hold promise for sustainable resource utilization in space habitats. Furthermore, the applications of space-tested microbial technologies on Earth can address environmental challenges and contribute to renewable energy production.

Biomedical sensors and diagnostics

Another technology area with an important role in space exploration is biomedical sensor technology. For example, the *Inspiration4* mission was the first outer space mission to use the Apple Watch to collect biometric data and measure the cardiovascular physiology of the crew while they were in flight. *See* Jones 2024, *supra*.

NASA's development of Nanosensor Array for Medical Diagnoses (US 10,566,089) is designed to detect biomarkers associated with certain diseases. The '089 patent states that these sensors provide a non-invasive method for fast and accurate diagnosis of diseases. Such methods may be useful for monitoring astronaut health and diagnosing diseases during space missions.

Opportunity: Reliable biomedical sensors and diagnostics can be important tools for monitoring astronaut health and ensuring timely medical interventions in space. Moreover, the application of space-tested biomedical technologies in healthcare on Earth may improve disease detection and patient care.

Conclusion

The fusion of biotechnology and space exploration offers opportunities for discovery and innovation. By navigating the complexities of biotechnology in outer space, government, non-profit, and private sectors alike can foster innovation, promote collaboration, and contribute to the exploration of the final frontier.

The burgeoning global space economy is projected to reach $1.8 trillion by 2035. *See* Acket-Goemaere et al., "The $1.8 trillion opportunity for global economic growth," McKinsey & Company. April 8, 2024. (available here: https://mck.co/3WODYmt). Thus, in this era of cosmic exploration, the sky is not the limit — it is only the beginning.

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