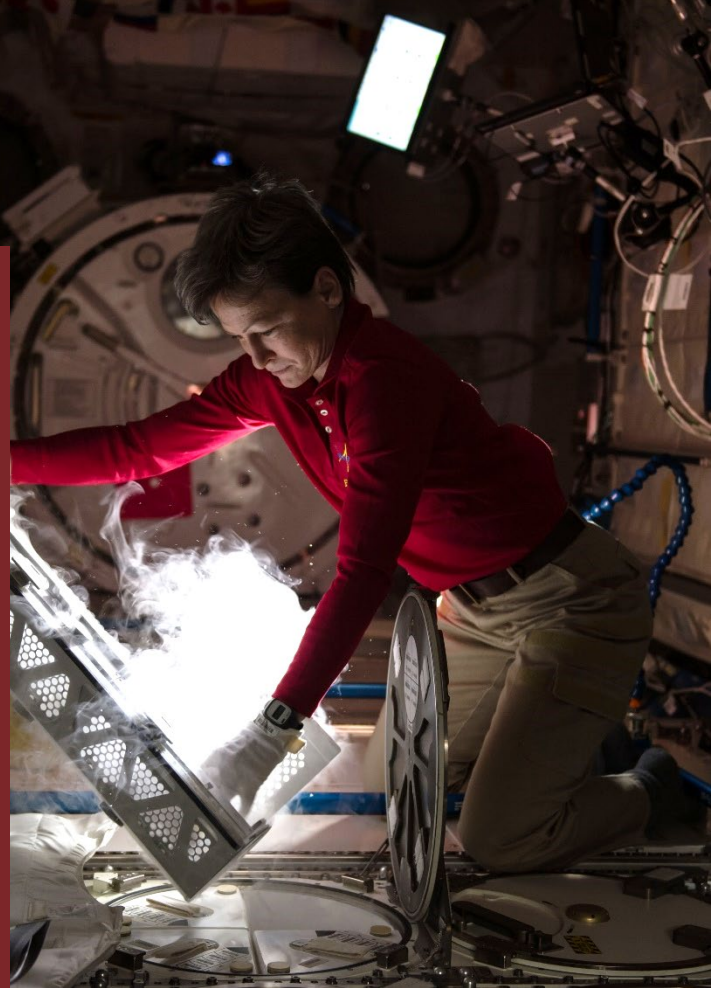


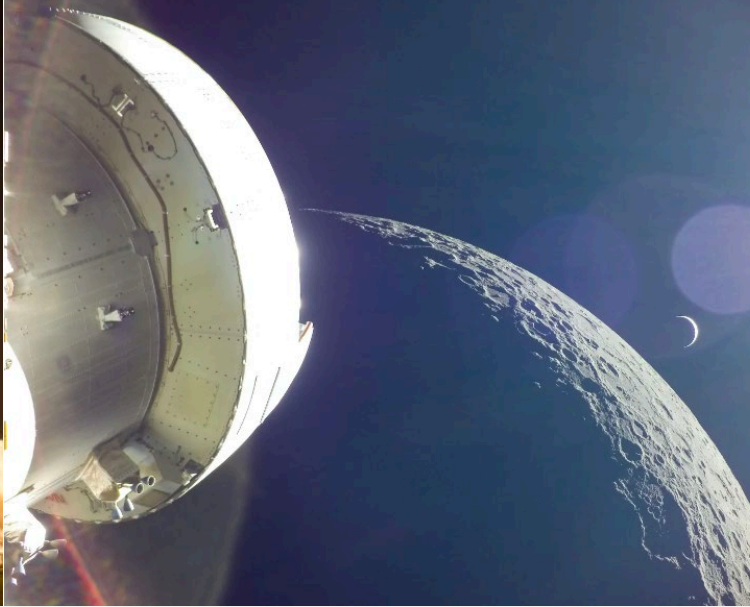
Thriving in Space - Ensuring the Future of Biological and Physical Sciences Research

A Decadal Survey for 2023-2032

Robert J. Ferl and Krystyn J. Van Vliet, Co-Chairs

nationalacademies.org/bps-decadal





The next decade heralds exciting
new advances as we move to
explore the Moon and Mars.

The space ecosystem is expanding rapidly

The next decade will involve:

- More people
- More destinations, including the Moon and Mars
- Longer duration missions
- More activity types
- More commercialization





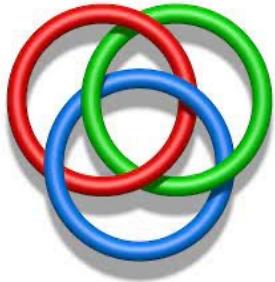
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Melding of science across the mission space
Rethink the MET opportunities
Specificity of location and broad sampling*

Steering Committee, Expert Panels, & Community Input



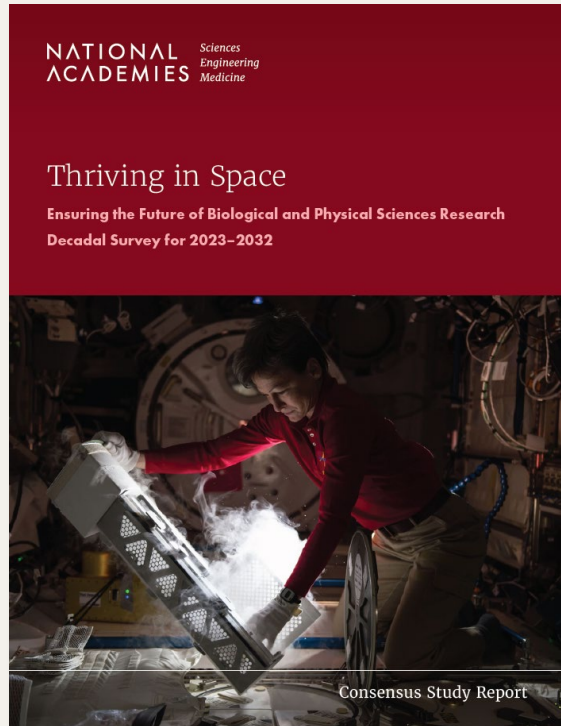
Biological Sciences
Physical Sciences
Engineering and Science
Interface

Steering Committee: 18 experts from across the US and the **BPS** disciplines

Panels: 50+ experts, organized in working groups that mixed **BPS** disciplinary expertise on the current state of the field, future science priorities, and feasibility

Community Input: 250+ topical concept papers; 60+ research campaign concept papers; 2+ years of public meetings with government + industry experts

Report Snapshot



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- Summary
- 1: Introduction
- 2: Current State of Knowledge in BPS
- **3: Key Science Themes and Questions**
- 4: Science to Enable Space Exploration
- 5: Science Enabled by the Space Environment
- **6: Research Campaigns**
- 7: Infrastructure, Access, and Community

3	11	2	25
Science Themes	Science Questions	Research Campaigns	Recs

Focus on Key Scientific Questions



Key Science Themes

ADAPTING TO SPACE



What fundamental processes change when away from Earth?

LIVING AND TRAVELING IN SPACE



What does it take to occupy space environment over the long haul?

PROBING PHENOMENA HIDDEN BY EARTH



What principles are hidden by gravity or revealed only by being in space?

Key Science Themes

ADAPTING TO SPACE



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What does it take to occupy space environment over the long haul?

PROBING PHENOMENA HIDDEN BY EARTH



What principles are hidden by gravity or revealed only by being in space **or on the Moon?**

Adapting to Space

Key Scientific Questions

- How does the space environment influence biological mechanisms required for organisms to survive the transitions to and from space, and thrive while off Earth?
- How do genetic diversity and life history influence adaptation to the space environment?
- How does the space environment alter interactions between organisms?



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Living and Traveling in Space

Key Scientific Questions

- What are the important multi-generational effects of the space environment on growth, development, and reproduction?
- What principles guide the integration of biological and abiotic systems to create sustainable and functional extraterrestrial habitats?
- What principles enable identification, extraction, processing, and use of materials found in extraterrestrial environments to enable long-term, sustained human and robotic space exploration?
- What are the relevant chemical and physical properties and phenomena that govern the behavior of fluids in space environments?



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Probing Phenomena Hidden by Gravity or Terrestrial Limitations

Key Scientific Questions

- What are the mechanisms by which organisms sense and respond to physical properties of surroundings, and to applied mechanical forces including gravitational force?
- What are the fundamental principles that organize the structure and functionality of materials, including but not limited to soft and active matter?
- What are the fundamental laws that govern the behavior of systems that are far from equilibrium?
- What new physics, including particle physics, general relativity, and quantum mechanics, can be discovered with experiments that can only be carried out in space?



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Connect to societal impact with Research Campaigns



New **Research Campaigns** with audacious goals will help drive solutions to the key science questions within the decade and make best use of missions to the Moon and Mars.

Research Campaigns

BLISS



Bioregenerative Life Support Systems

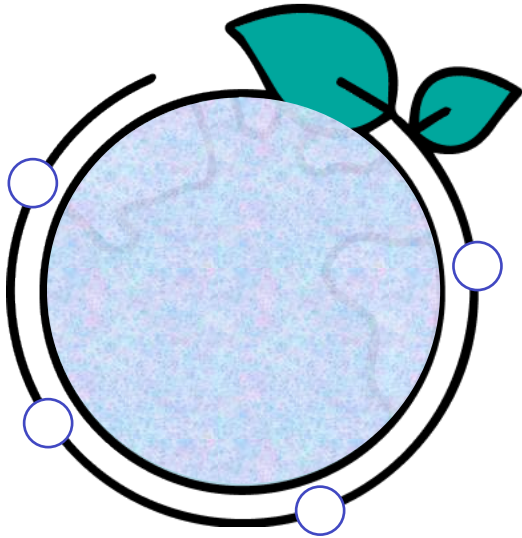
MATRICES



Manufacturing mATeRials and ProcessEs for Sustainability in Space

Research Campaigns

BLiSS Goals



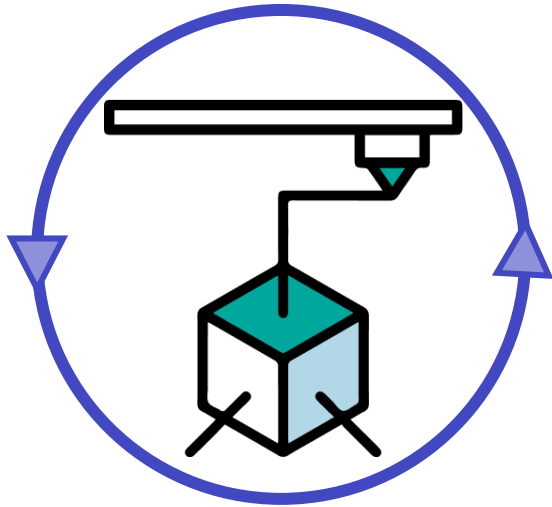
In the context of global competition for LEO research with Earth benefits

1. Self-sustainable system to produce food, clean water, renew air, process waste, and create critical materials to meet the challenges of long-duration space missions.



Research Campaigns

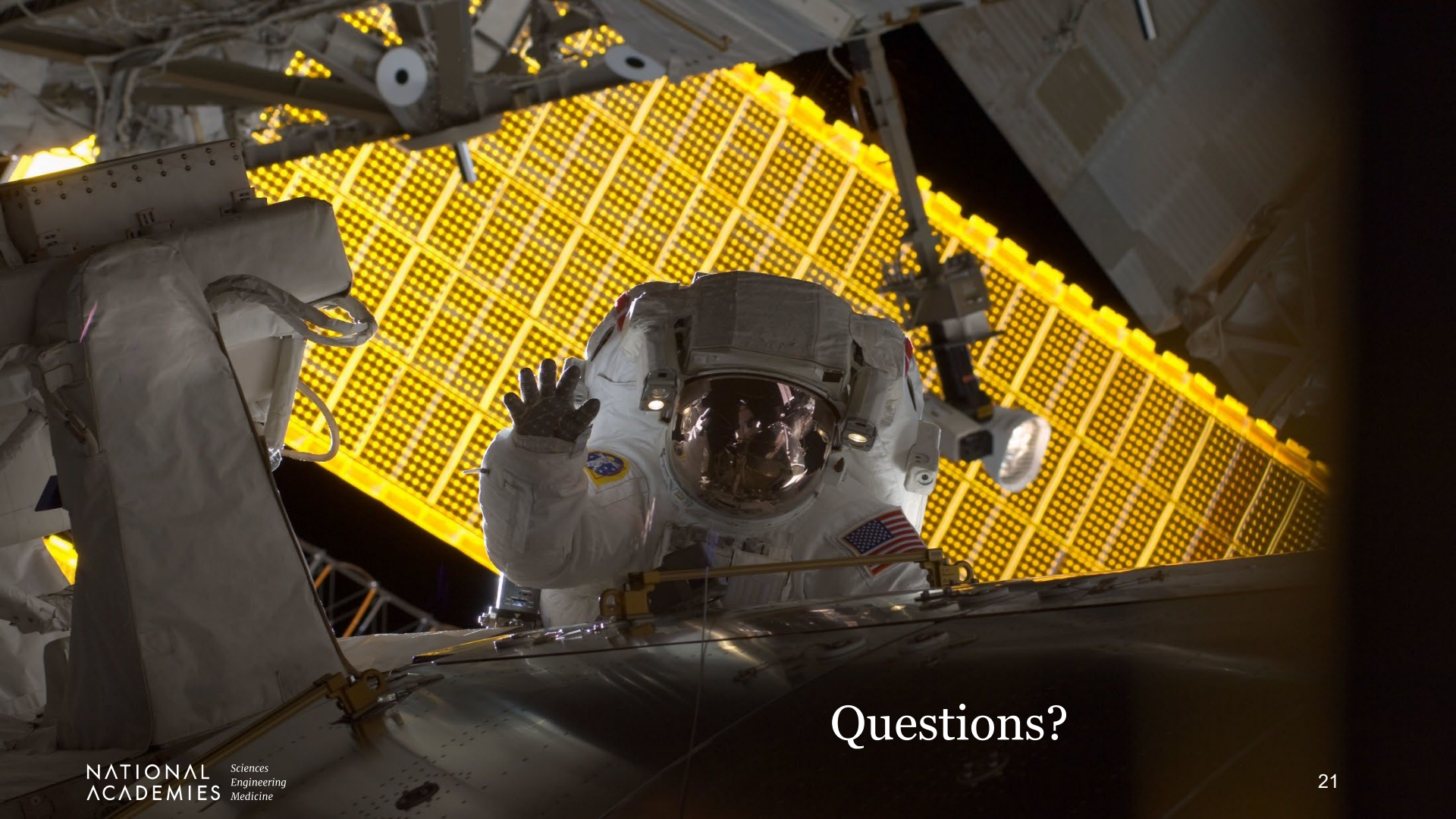
MATRICES Goals



In the context of global competition for resource use & manufacturing expertise off-Earth

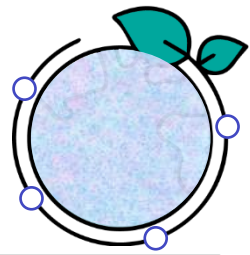
1. Learn how materials and energy interact in non-terrestrial environments, and use that knowledge to design infrastructure for responsible space exploration.



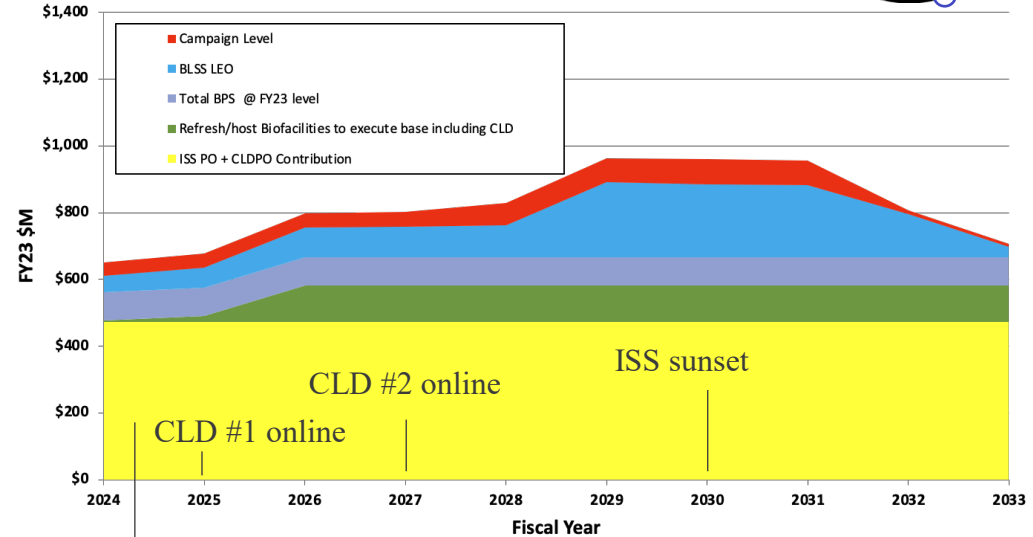


Questions?

Research Campaign Assumptions



- At least 2 commercial lunar destinations (CLDs) *for scientific research* use this decade. Otherwise, US severely disadvantaged on prep for Moon to Mars.
- Launch costs excluded from *BPS research program* cost estimates, consistent with current practice
- Coordination services provided by US Program Office, for LEO and other research destinations



ISS+CLD PO CLD Contribution: ROM estimate of the allocation of launch and return vehicle services, crew time and integration and operations services provided for the total BPS program