Space Bio-Manufacturing

Bio-Manufacturing for Deep Space Exploration

NASA’s Space Technology Research Institute:
The Center for the Utilization of Biological Engineering for Space (CUBES)

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12/05/2017
NASA/NAC Meeting
Presentation Topics

Background
• NASA’s needs for *In situ* manufacturing, *In situ* resource utilization and life support
• The potential of biological systems

CUBES – Center for the Utilization of Biological Engineering in Space
• Team members
• Project goals and research strategy
• Expected outcomes
Life Off Earth

- Temperature
- Air
- Food
- Water
- Pressure
- Radiation Protection
- Waste Removal
- Gravity

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Future Missions Need a Different Approach

- Short crew duration
- Frequent resupply of food, water, O₂, medical supplies, replacement parts
- Emergency return to Earth
- No ET planetary protection requirements

- Extended crew durations
- Infrequent or no resupply of food, water, O₂, medical supplies, replacement parts
- No emergency return to Earth
- Possibly strict planetary protection requirements
Future Mission Sustainability

- **In situ Resource Utilization (ISRU)** generates supplies from local resources.
- **In situ Manufacturing (ISM)** provides capability to make needed chemicals, fuels, building materials, pharmaceuticals, etc. on-site and on-demand.
- **Closed-loop life support systems** treat and recover valuable resources via regenerative air, wastewater and solid waste processing systems.
- **Food production** will be required to supply nutritional needs not met by current food provisioning systems. Eventually all food may be produced *in situ*.
- **Space medicine** systems will require the ability to monitor and maintain the health of the crew under very adverse conditions.
- These systems require increased **reliability and self-sustainability**, and decreased mass, power, volume and consumable use.
In situ Production of Mission Products
Potential Biological Products:

• Food – plants and microbial products
• Vitamins, nutraceuticals
• Enzymes, flavors, preservatives
• Therapeutics/pharmaceuticals
• Polymers – plastics for parts, habitat construction, radiation protection
• Fuels – hydrocarbons, nitrogen-based
• Primary chemicals for various product synthesis
• Adhesives/biocement - construction
• Specialized function biomolecules:
  - e.g., Carbonic anhydrase for CO$_2$ management
Research Challenges:

- Novel, high efficiency, engineered microbes/plants
- Use of unique substrates – *in situ* media generation
- Novel bioreactor designs
- Product harvesting and purification strategies
- Minimization of inputs/wastes
- Reduction and consolidation of separate unit operations
- Enhanced microbial storage and reanimation techniques
- Maintaining pure cultures/controlled consortia with minimal intervention
- Increased genetic and phenotypic stability
- Interfacing biology with inanimate components
1. *In situ* Microbial Media Production
   - Conversion of carbon dioxide, water, and other needed resources to microbial substrates (“*In situ* media” production) - supports rapid heterotrophic growth
   - Supporting physico-chemical and biological methods that process local resources

2. *In situ* Production of Mission Products
   - Developing microorganisms with targeted metabolisms to produce target products using *In situ* media
   - Novel systems for growth and harvesting of target products
   - Demonstration of manufacture of products for mission applications

3. *In situ* Food Production
   - Increase yield, volume efficiency, and photosynthetic efficiency
   - Enhance overall nutritional attributes
   - Enhance secondary product recovery from inedible biomass
Research alignment with NASA Technology Roadmaps:

- **TA07 Human Exploration Destination Systems** - TA7.1 In Situ Resource Utilization (the MMFD, BBMD, and FPSD will all use such inputs), TA7.2 Sustainability and Supportability (the MMFD, BBMD, and FPSD will all use sustainable resource recycling), TA7.4 Habitat Systems (CUBES will develop a semi-autonomous proof-of-concept biomanufacturing demonstration), and TA7.6 Cross-Cutting Systems (the BBMD additive manufacturing technology will be designed for scaling assembly).

The Center for the Utilization of Biological Engineering for Space

Lead Institution: University of California Berkeley

Collaborating Institutions:
- Stanford University
- University of California – Davis
- Utah State University
- University of Florida
- Physical Sciences Inc.

CUBES

Mission Statement (CUBES):
- Support innovation in the life sciences.
- Create and manage an infrastructure; seed investment.
- Transform new systems to demonstrate commercialization.
- Engage with and create clear, actionable, and focused institutional mechanisms.

Mission Objectives (CUBES):
- Transform new systems to demonstrate commercialization.
- Engage with and create clear, actionable, and focused institutional mechanisms.

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NASA/CUBES Kick-off Meeting held 10/19-20/2017

5 years - up to $3M/year budget
CUBES Team

CUBES Investigators:

Adam P. Arkin, PI, UC Berkeley
Amor A. Menezes, Co-I (Science PI), U Florida*
Craig S. Criddle, Co-I (Institutional PI), Stanford U*
Karen A. McDonald, Co-I (Institutional PI), UC Davis*
Lance C. Seefeldt, Co-I (Institutional PI), Utah State U*
Aaron J. Berliner, Other Professional, UC Berkeley
Bruce Bugbee, Co-I, Utah State U
Douglas S. Clark, Co-I, UC Berkeley
Devin Coleman-Derr, Co-I, UC Berkeley
Kalimuthu Karuppanan, Co-I, UC Davis
Somen Nandi, Co-I, UC Davis
Robert M. Waymouth, Co-I, Stanford U
Peidong Yang, Co-I, UC Berkeley

* = Research Division Leads
Vision Statement:

The Center for the Utilization of Biological Engineering in Space (CUBES) will leverage partnerships between NASA, other federal agencies, industry, and academia to:

• Support biomanufacturing for deep space exploration;
• Create an integrated, multi-function, multi-organism biomanufacturing system for a Mars mission; and
• Demonstrate continuous and semiautonomous biomanufacture of fuel, materials, pharmaceuticals, and food in Mars-like conditions.
Research Objectives:

• Harness Mars atmospheric and regolith resources for downstream biological use;

• Create outputs like propellants and building materials that are fundamental enablers of any space mission;

• Synthesize food and pharmaceuticals *in situ*, to allow these long-duration space missions to be manned;

• Perform space and complex systems engineering, to analyze, guide, test, improve, and integrate the above.
CUBES Strategy

Approach: Four integrated research divisions

- **Systems Design and Integration (SDID):** optimally allocate and utilize Mars resources, to tightly integrate and automate internal processes, and to satisfactorily achieve performance per mission specifications (Menezes)
- **Microbial Media and Feedstocks (MMFD):** harness *in situ* resources, decontaminate and enrich regolith, and transform human/mission wastes to media and feedstocks for utilization by downstream processes (Seefeldt)
- **Biofuel and Biomaterial Manufacturing (BBMD):** produce propellants, biopolymers, and chemicals from media and feedstocks, recycle products at end-of-life, and use generated biopolymers in 3D-printing (Criddle)
- **Food and Pharmaceutical Synthesis (FPSD):** engineer plants and microbes for use by astronauts. (McDonald)

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CUBES’ individual approaches to media production, mission product manufacture, and food and pharmaceutical synthesis, amplified by a focus on integration and optimization, will lead to a strong data-driven, technologically-backed platform for space biomanufacturing.

• Engineered microbes to convert limited, marginally accessible Martian feedstocks, such as atmospheric gases at low partial pressure and nutrients from contaminated/toxic land, into commodities;
• Novel biologically-coupled nanotechnologies to fix available carbon and nitrogen and to transfer energy into biosynthetic processes;
• Refined plants and plant microbiomes that grow in restricted space, light, water, and nutrients, and that can still provide substantial yields of nutritive foods;
• Biologically-produced pharmaceuticals, cellular treatments/therapeutics, and materials for on-demand diverse 3D-printing applications;
• Optimized, integrated operation of these processes.
Questions?