



Space Technology Mission Directorate
Game Changing Development Program
PPBE 22 – Existing Projects – New Content

John Hogan| FY20 Synthetic Biology| 02.28.20

Existing Project - BioNutrients

New Additional Content



- **Summarize where the technology will be at the current end of project**
 - Delivered and tested in low earth orbit a platform technology for the on-demand microbial manufacturing of multiple human nutrients to mitigate nutrient deficiencies in the current pre-packaged food system for long duration missions.
 - Conduct 5-year test of a production pack system that enables required nutrient production after long-duration storage of the microorganisms and media, requires minimal mass and volume, and complies with required food safety requirements.
 - Develop and flight test a Hazard Analysis and Critical Control Point (HACCP) plan and in-space monitoring methods for ensuring food safety requirements for future implementation during missions.
- **Summarize additional content**
 - Automation of nutrient production pack operation to ensure product consistency, reduce crew time, and monitor/maintain safety.
 - Work with HRP Food Systems (JSC) to go beyond demonstration to provide a viable edible product and associated safety protocols.
 - Identify/develop new products to support exploration missions – additional nutrients, pharmaceuticals, and high value compounds.
- **Provide a clear statement of “why” the additional content needs to be developed and the importance/nature of additional content being proposed**
 - Automation will allow for production with minimal crew intervention, and can decrease human error and variability.
 - Nutrient requirements are evolving, with an expectation that multiple compounds and means of delivery of those compounds will become required as the nutrient and pharmaceutical requirements mature.
 - Developing a method to deliver an edible microbial food product in flight and consumption by crew will be instrumental to identifying and addressing challenges in palatability, acceptability, safety, and reliability.

Existing Project – CO₂-Based Manufacturing

New Additional Content



- **Summarize where the technology will be at the current end of project**
 - A ground tested, reduced gravity-compatible prototype with “space-ready” microbe(s), producing carbonic anhydrase from CO₂-derivable feedstock. (TRL 3/4)
 - Use case scenarios and systems analysis for Lunar and Martian surface missions.
- **Summarize additional content**
 - Refinement of production platform for Lunar or Martian surface mission deployment (increasing overall system TRL to 4, some components to 5).
 - Facilitate development and integration of newly developed SOA CO₂ conversion technologies to increase production potential (e.g. sugars) of microbial growth substrate.
 - Novel product identification and production via microbial engineering (e.g. nutrients, pharmaceuticals, food, additional enzymes/products).
- **Provide a clear statement of “why” the additional content needs to be developed and the importance/nature of additional content being proposed**
 - To meet the evolving in-space manufacturing requirements of future Lunar and Martian surface missions, providing a test platform for reliable, safe, low ESM CO₂-based manufacturing capabilities.

BioNutrients

New Additional Content - Approach



➤ Describe how and when technology will be infused in future systems

- Describe how the technologies work together and are used in system performance
 - Expansion of nutritional products, assessment of palatability/acceptability and use of products by crew on ISS. This supplements the prepackaged food system, addressing critical nutrient degradation in long duration missions.
 - Automation prototyping to decrease crew time, increase safety, performance and utility of BioNutrients products and platform.
 - Supports draft HRP Food Roadmap that proposes inflight testing (including Lunar surface) in the 2028/29 timeframe.
- Describe any known interface requirements and/or interdependencies for other technologies/capabilities
 - Requires water (clean, potable), waste containment/recycling (solid and vapor), and pressurized cabin space, power, crew, controlled temperature environment (may be cabin).

➤ Describe how the additional content will be accomplished

- In-house development and flight testing, coordination with HRP Food System Program.
- Pull from Industry/Academia – STTR Phase II Sustainable Bioproducts, Center for the Utilization of Biological Engineering for Space (CUBES).

CO₂-Based Manufacturing

New Additional Content - Approach



➤ Describe how and when technology will be infused in future systems

- Describe how the technologies work together and are used in system performance
 - CO₂-based manufacturing platform refinement and continued development for Lunar/Martian surface missions will support future bioreactor testing and *in situ* resource utilization of CO₂.
 - Technology approach supports increased sustainability missions, including proposed Lunar base establishment in 2028 and future Mars missions.
 - Project product carbonic anhydrase is targeted enhancement for liquid amine CO₂ removal system for life support.
- Describe any known interface requirements and/or interdependencies for other technologies/capabilities
 - Requires power, water/hydrogen, concentrated CO₂ source, media supplements, thermal control, radiation protection, pressurized volume.

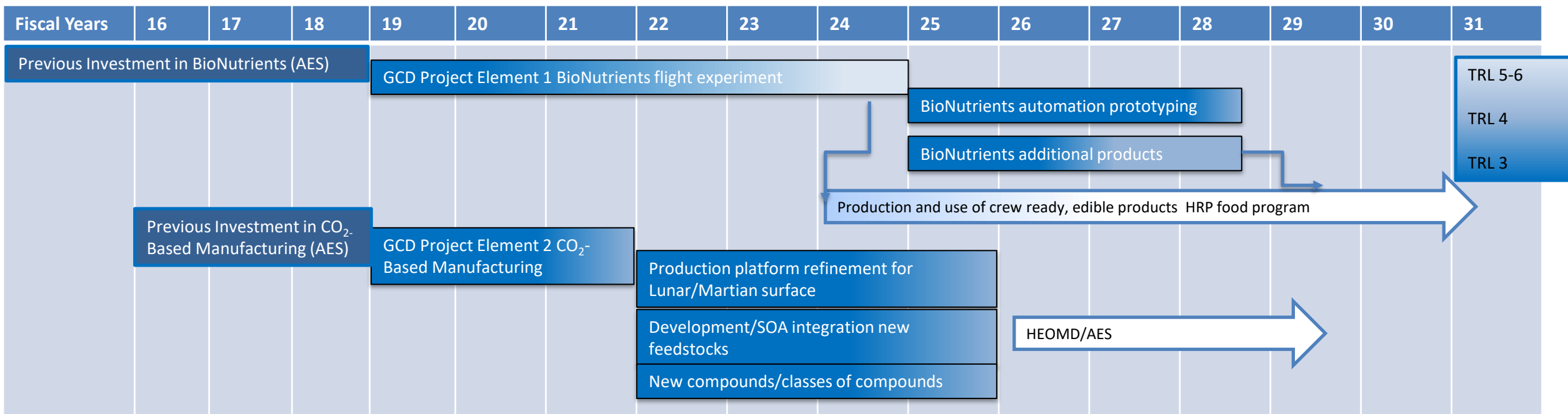
➤ Describe how the additional content will be accomplished

- In-house development: engineered organisms, bioreactors and mission implementation assessment.
- Leverage cooperative agreement with Kanan lab, Stanford University - CO₂ conversion to microbial substrates. Potentially other academic/industrial partners.
- Leverage NASA CO₂ Conversion Centennial Challenge – CO₂ conversion to sugar feedstock (currently in Phase II of competition).

Technology Development & Transition Timeline

➤ Customers

- Current: AES Life Support Systems
 - Carbonic Anhydrase for liquid amine CO₂ removal, directed evolution optimization (funded by AES)
- Potential: HEOMD HRP, AES Life Support Systems
 - HEOMD HRP: Nutrients, yogurt-based food products, pharmaceuticals
 - AES Life Support Systems: CO₂-Based Manufacturing of carbonic anhydrase, additional products





Additional Cost, Schedule, Deliverables, Key Milestones (Overview)

	FY 22				FY 23				FY24				FY25			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
Go/ No-Go Gates	◆ TAPR/KDP CO ₂ -Based Manufacturing												◆ TAPR/KDP BioNutrients			
Bio Nutrients													New Products Phase A review/KDP ◆ Edible products Phase A review/KDP ◆ Product downselect ▲ Automation Phase A review ▲			
Cost																
CO ₂ - Based Manufact uring	Production platform refinement for Lunar/Martian surface SRR Gen-2 ▲ Gen-2 bioreactor components test ▲ Gen-2 integrated bioreactor test ▲ Development/SOA integration of new feedstocks Phase A/KDP ◆ Feedstock and Product downselect ▲ New feedstocks Integration test ▲ New strain(s) test ▲ New compounds/classes of compounds Phase A review/KDP ◆ ▲ New compound/class downselect Bioengineer new compound ▲ New strain(s) with new Product test ▲															
Cost																
Annual Cost	(1.3 FTE)				(1.3 FTE)				(1.3 FTE)				(4.5 FTE)			