S15.01 Plant Research Capabilities in Space

Lead Center: KSC
Participating Center(s): ARC, JPL, JSC

Scope Title

CO2 Collection and Dosing Technologies for Plant Chambers

Scope Description

Carbon dioxide is an essential gas to sustain plant photosynthesis. Spacecraft cabins with humans often have very high CO₂ levels (e.g., 2,000 to 7,000 ppm or 0.2 to 0.7 kPa on the International Space Station, ISS), and this has been used for CO₂ supply to open plant chambers like the Russian Lada and NASA’s Veggie unit. This does not provide precise control of the CO₂ concentration, however: the levels are always floating with the cabin, which makes it difficult to replicate for ground controls and optimize for plant growth. NASA Advanced Plant Habitat (APH) is a closed chamber capable of tight CO₂ control, but instead of using cabin air, compressed cylinders of CO₂ are shipped to space, adding mass consumables and pressurized containers to operate APH.

NASA needs a system for selectively scrubbing CO₂ from cabin air, which can vary from 2,000 to 7,000 ppm (0.2 to 0.7 kPa), and then dosing or adding the CO₂ in a controlled fashion to closed plant chambers like APH to maintain constant CO₂ concentrations. Such a capability could eliminate the need for shipping compressed CO₂ cylinders continuously to ISS to operate APH and/or stabilize fluctuating CO₂ levels for open chambers like Veggie. A starting example of such an approach might be something like the ISS Carbon Dioxide Removal Assembly (CDRA), which uses zeolite beds to remove and then release CO₂. For closed plant chambers, the technology would need to be miniaturized, require low power, and capable of being attached or connected directly to the chamber or its internal air plenum and then releasing the CO₂ to inside of the chamber to balance CO₂ removal by the plants. Internal plant chamber concentrations are typically optimal between 1,000 and 2,000 ppm (0.1 and 0.2 kPa), but the plants rapidly remove the CO₂ during the light cycle while they are photosynthetically active; hence the need for controlled CO₂ additions.

Expected TRL or TRL Range at completion of the Project

2 to 5

Primary Technology Taxonomy

Level 1
TX 08 Sensors and Instruments

Level 2
Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype

Desired Deliverables Description

The Phase I project should focus on feasibility and proof-of-concept demonstration. The required Phase I deliverable is a report documenting the proposed innovation, its status at the end of the Phase I effort, and the evaluation of its strengths and weaknesses compared to the state of the art.

Following Phase II, a working prototype that could be attached to a closed chamber similar to the NASA APH would be desirable.

State of the Art and Critical Gaps

The state of the art is to send compressed CO\textsubscript{2} gas in cylinders into space and use these to add controlled amounts to closed chambers like APH. For open chambers like Veggie, the SOA is using cabin air for CO\textsubscript{2} supply, but this does not provide very precise CO\textsubscript{2} control. The proposed capability could replace the need to deliver compressed CO\textsubscript{2} to APH and help "smooth" or buffer CO\textsubscript{2} changes in Veggie.

Relevance / Science Traceability

Accurate CO\textsubscript{2} control is essential for careful research and optimal growth of plants in space. This is possible by supplying compressed CO\textsubscript{2} from Earth, but this is costly and is ironic when the closed plant chambers are already surrounded by a cabin atmosphere with very high levels of CO\textsubscript{2}.

References


Scope Title

Miniature Elemental Analyzer for Water Analysis and Support of Plant Research

Scope Description

As plant-growing systems mature and expand for future exploration missions and enhanced research capabilities, the ability to generate, analyze, and manage nutrient (fertilizer) solutions will increase. As of now, we can only take “grab” samples of water from systems like the Advanced Plant Habitat (APH) or the proposed Passive Orbital Nutrient Delivery System (PONDS) nutrient delivery system for Veggie, return them to Earth, and then analyze
them for the elemental composition. An in-situ capability is needed to analyze plant nutrient solutions or feed water to better understand and manage plant nutrient delivery on a near-real-time basis. Inductively coupled plasma (ICP) spectroscopy is one proven approach for elemental analysis, but ion chromatography (IC) or high-performance liquid chromatography (HPLC) might have overlapping capabilities. Regardless, the technology would need to be robust and miniaturized, operate with low power, and have minimal consumables to augment plant growth and research capabilities for the future missions. The system would also need to be safe for operating in spaceflight environments. Ideally, the technology could provide rapid analysis of elemental composition of water samples. Essential elements for plants include (in approximately descending order): N, K, Mg, Ca, P, S (all typically in tens to hundreds of parts per million), and Mn, Fe, Cl, B, Zn, Cu, and Mo (all typically in parts per billion). Detection of as many of these elements as possible would be desirable. In addition, it would be desirable to detect other non-essential elements, such as Ni, Cr, Ag, V, and I, that might be contaminants from chamber materials, plumbing, or supply water. Discrimination between ionic species (e.g., NH₄ and NO₃ forms of nitrogen) would be helpful but not required. A miniaturized elemental analyzer/sensing capability could also have applications beyond those just for plants, where knowledge of the elemental composition of fluids, such as urine or tissue samples, could provide valuable data for supporting research or habitat operations.

**Expected TRL or TRL Range at completion of the Project**

2 to 4

**Primary Technology Taxonomy**

**Level 1**

TX 08 Sensors and Instruments

**Level 2**

TX 08.3 In-Situ Instruments/Sensor

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype

**Desired Deliverables Description**

The Phase I project should focus on feasibility and proof-of-concept demonstration. The required Phase I deliverable is a report documenting the proposed innovation, its status at the end of the Phase I effort, and the evaluation of its strengths and weaknesses compared to the state of the art.

A Phase II deliverable may include a working prototype or engineering development unit (EDU) to demonstrate a miniaturized elemental analyzer system as part of a plant-growth system like the APH, the proposed PONDS watering systems for growing plants in the Veggie plant chamber on ISS, or future proposed “hydroponic” systems being considered for growing plants in space.

**State of the Art and Critical Gaps**

Laboratory-scale ICP or IC systems that operate with a plasma torch or high pressure to get the needed emission spectra are a standard state-of-the-art approach for elemental analysis.

**Relevance / Science Traceability**

As longer duration plant research tests are conducted in space, there will be a need for addition of nutrient or fertilizer solutions to sustain the plants; for example, the current APH test with chili peppers is scheduled to go for >100 days. Although this uses time-release fertilizer, in situ water analysis could provide information on backwash of nutrients into the water delivery system and verification of the water quality of cabin potable water used for the
tests. For the proposed PONDS watering system for Veggie, initial nutrients will come from time-release fertilizer as well, but having in situ nutrient/elemental analysis could assess needs for further nutrient additions. For proposed "hydroponic" systems for space, capabilities to analyze nutrient solutions would be needed throughout the experiment or plant production trial.

References