International Partnership Opportunities in a Lunar Surface Plant Production Demonstrator

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Summary

NASA and its international partners are planning to return humans to the Moon starting in the mid-2020s under the Artemis program, with the intention of establishing a sustainable human presence on the lunar surface (NASA, 2021). Although it is certain that traditional physical-chemical life support systems and pre-packaged foods will be relied upon by early lunar surface crews, sustained presence will eventually require the incorporation of *in-situ* food production. Demonstrating the reliability of these biological systems under lunar conditions, such that confidence in such systems is firmly establish, is the first logical step towards a lunar surface plant production system.

Canada has a strong heritage in bioregenerative/advanced life support and, due to its harsh climate, controlled environment crop production in general (Bamsey et al., 2009). Following the 2019 release of a new national space strategy (Government of Canada, 2019) the Canadian Space Agency (CSA) has initiated a number of activities in the food production domain that have the potential to benefit future space crews, while at the same time inform and improve terrestrial food production. Following detailed analysis, and with the increased international focus on the lunar surface (ISECG, 2020), the CSA has prioritized the lunar surface as its destination of choice for its food production activities.

There is an opportunity for NASA to work with the CSA, and possibly other partners, to develop a lunar surface plant production demonstrator that could serve as a venue for larger-scale space biology research and a valuable technology demonstrator for plant production systems that will support future space crews. This facility could also serve as a technology transfer and collaboration hub for participating nations.

Context

As space missions move further and further away from Earth and increase in duration, the importance of reducing resupply of crew consumables, i.e., air, water and food, increases significantly. Bioregenerative life support systems, in particular plant production systems, have the potential to close these three resource loops, while providing psychological benefits to long-duration crews. Space technology for low mass, low energy, low waste systems is also highly applicable to terrestrial food production systems aimed at supporting food production in Northern and remote communities or vertical farms in urban centers.

Canadian and U.S. researchers have been collaborating in the domain of bioregenerative life support, and more specifically space agriculture, for decades (Bamsey et al., 2009; Wheeler, 2017; Levine et al., 2008; Graham et al., 2015; Wheeler et al., 2011). Collaboration has included wide array of hypobaric plant growth experiments, operation of a High Arctic greenhouse, plant health imaging, International Space Station science including via the Advanced Plant Experiments on Orbit – Cambium (APEX-Cambium), as well as inter-agency (NASA/USDA/University of Guelph) crop development activities including spaceflight compatible 'tree' fruit (plums), and frequent personnel exchanges. More recently, the CSA and NASA have been collaborating on the Deep Space Food Challenge, the first case of NASA teaming with an international partner in the history of its NASA Centennial Challenge Program. Collaborative work in this domain has also extended to other countries, including the German Aerospace Center (DLR) through the EDEN ISS Antarctic greenhouse project in which Canadian and U.S. researchers have been involved.

CSA Food Production Initiative

To concurrently advance the space and terrestrial applications of food production, CSA has initiated a Food Production Initiative based on national priorities and competency areas as illustrated in the proceeding figure.

The working vision statement for the CSA Food Production Initiative is:

By the mid-2030s, Canada will have developed food production capabilities for long-duration human spaceflight and provided one or more critical systems to an international lunar surface food system partnership.

A key element of this working vision statement is the stated priority on international collaboration to specifically achieve the design and deployment of a lunar surface food production system.

Current Activities

The CSA presently has a number of on-going and planned activities to advance its food production vision. These include:

- *Naurvik Initiative* ("Growing Place"): A joint effort between the Community of Gjoa Haven, Arctic Research Foundation, the National Research Council of Canada, Agriculture and Agri-Food Canada and the CSA that is presently operating a renewable energy plant production system in Gjoa Haven, Nunavut, that both benefits and enables local food production, while serving as a test-bed for food production technologies that may one day fly in space.
- *Deep Space Food Challenge*: A prize challenge co-organized by NASA, the CSA and the Canadian Privy Council Office's Impact and Innovation Unit (Impact Canada Initiative) that focuses on technologies to support food production for long-duration space missions as well as terrestrial food systems.

- *Food Production Topical Team*: An advisory group made-up of 40 leading Canadian and international (e.g., U.S., Germany) experts that guide and provide recommendations to the CSA on its developing Food Production Initiative.
- *Lunar Surface Exploration Initiative*: A multi-year initiative focused on preparatory activities to study major infrastructure contributions that Canada could consider making on the lunar surface. Lunar surface agricultural modules constitute one of the five prioritized areas for study. Concept studies and prototyping activities are planned in the near-term.

Other recent CSA activities have also supported activities that relate to plant production. For example, a recently completed Phase 0 'Lunar Exploration Agriculture Feasibility (LEAF)' study funded through the CSA's Lunar Exploration Accelerator Program (LEAP) focused on a small plant growth payload for a lunar lander.

Proposal for U.S. and Canadian Collaboration in a Lunar Surface Agricultural Module

A demonstrator consisting of a pressurized module outfitted with high-intensity plant production systems (e.g., LED lighting, hydroponic/aeroponics nutrient delivery systems, water recovery, automation, plant health monitoring) deployed on the lunar surface would allow system reliability to be improved before crew would depend on the produced food products as a recognized and essential part of their diets. Just as importantly, such an agricultural module would serve as an excellent venue to conduct plant growth and biological science research in the reduced gravity lunar environment. In particular, the scale of such a system (as a small to mid-sized pressurized module) would permit a scale-up of the science that is currently conducted in ISS-based facilities (e.g., Veggie, Advanced Plant Habitat).

Canada and the U.S. have been strong partners throughout the history of the human space flight program, including, the Space Shuttle program, the ISS and soon on the Gateway. Great potential exists to continue strengthening this highly successful collaboration to achieve common lunar surface science and engineering goals in a manner that enables efficiencies and rapidly advances the development of space agriculture technologies.

Therefore, it is proposed that NASA, the CSA, and a possible select group of other international partners (e.g., DLR) commence more detailed analyses for the design and future deployment of a lunar agricultural module. Technical exchanges and possible concurrent engineering studies would focus on defining the high-level requirements of such a plant production system, including estimated costs (assumed to be in the $1B-$3B USD range), appropriate schedule, concept of operations and an initial split of the potential work between potential partners. The CSA and the Canadian space exploration community would welcome the opportunity to contribute and collaborate with NASA in the design, development, deployment, and operations of a lunar surface agricultural module.

Furthermore, under this proposal NASA and the CSA would also strive to identify relevant milestones on the way to the achievement of this lunar surface plant production demonstrator module. This could include collaborating on ground-based testbeds (e.g., Naurvik or an more fully integrated ground-based test-bed) or the deployment of smaller-scale (<100 kg) lunar surface plant growth payloads for science and technology demonstration.

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