EDEN ISS

Ground Demonstration of Plant Cultivation Technologies and Operation in Space

For Safe Food Production on-board ISS and Future Human Space Exploration Vehicles and Planetary Outposts

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List of participants:

Participant No.	Participant organisation name	Short name	Type	Country
1	Deutsches Zentrum für Luft- und Raumfahrt e.V.	DLR	Non-profit	Germany
2	LIQUIFER Systems Group GmbH	LSG	SME	Austria
3	Consiglio Nazionale delle Ricerche	CNR	Non-profit	Italy
4	University of Guelph	UoG	Academic	Canada
5	Alfred-Wegener-Institut für Polar- und Meeresforschung	AWI	Non-profit	Germany
6	EnginSoft S.p.A.	ES	SME	Italy
7	Airbus Defence and Space	AST	Industry	Germany
8	Thales Alenia Space Italia S.p.A.	TAS-I	Industry	Italy
9	Aero Sekur S.p.A.	AS	SME	Italy
10	Stichting Dienst Landbouwkundig Onderzoek	DLO	Academic	The Netherlands
11	Heliospectra AB	HS	SME	Sweden
12	Limerick Institute of Technology	LIT	Academic	Ireland
13	Telespazio S.p.A.	TPZ	Industry	Italy

Executive summary

Humanity's plans to further explore space require the development of bio-regenerative life support systems (BLSS) fully incorporated into space stations, transit-vehicles and eventually in habitats on the Moon and Mars. These concepts aim to decrease the (re-)supply mass by (re-)generating essential resources for humans through biological processes. Within a BLSS, the cultivation of higher plants takes a crucial role as they can contribute to all major functional aspects (e.g. food production, carbon dioxide reduction, oxygen production, water recycling and waste management). Furthermore, fresh crops are not only beneficial for human physiological health, but also have a positive impact on crew psychological well-being. Adding up these features, higher plants represent a unique asset that makes the investigation of their cultivation in closed systems an essential endeavour. However, cultivation in closed environments is challenging and several key technologies necessary for space-based plant production are not yet space-qualified or remain in early stages of development. The proposed EDEN ISS project foresees development and demonstration of higher plant cultivation technologies, suitable for future deployment on the International Space Station (ISS) and from a long-term perspective, within Moon and Mars habitats. The focus on key technologies and procedures associated with higher plant cultivation for food production guarantees a higher scientific outcome than spreading the research focus too broadly.

The EDEN ISS consortium will design and test essential CEA technologies using an International Standard Payload Rack (ISPR) cultivation system for potential testing on-board the ISS. Furthermore, a Future Exploration Greenhouse (FEG) will be designed with respect to future planetary BLSS deployments. The technologies will be tested in a laboratory environment as well as at the highly-isolated Antarctic Neumayer Station III, operated by the Alfred Wegener Institute. A small and mobile container-sized test facility will be built in order to provide realistic mass flow relationships for the ISPR section and FEG. In addition to technology development and validation, food safety and plant handling procedures will be developed. These are integral aspects of the interaction between the crew and plants within closed environments. In this sense, the ISS can be seen as a test-bed for long-duration space missions and future planetary outposts.

The EDEN ISS consortium is comprised of the leading European experts in the domain of human spaceflight and controlled environment agriculture (CEA). We are proud to unveil the partnership between Airbus Defence and Space and Thales-Alenia Space, who have joined together in this unique consortium to further push the boundaries of extra-terrestrial greenhouse technologies. The consortium also consists of the top international scientists in the field of CEA from Canada (and furthermore Russia, USA and Japan through the Scientific Advisory Board). The project reflects a multidisciplinary group of experts representing aerospace engineering, agriculture, horticulture, microbiology, polar and marine research, food science, medicine, and psychology.

Aims:
The overall goal of EDEN ISS is the adaptation, integration and demonstration of higher plant cultivation technologies and operation procedures for safe food production on-board ISS and for future human exploration missions. The following key technologies and procedures will be advanced beyond the state-of-the-art:

- Nutrient delivery systems
- LED lighting systems
- Bio-detection and decontamination systems
- Food quality and safety procedures
- Operation procedures for safe food production

Objectives:
Due to the necessity of validating key technologies for space greenhouses under mission relevant conditions and with representative mass flows, the EDEN ISS consortium defined six objectives:

1. **Manufacturing a space analogue mobile test facility**
2. **Integration and test of an International Standard Payload Rack plant cultivation system for future tests on-board ISS and a Future Exploration Greenhouse for planetary habitats**

3. **Adaptation, integration, fine-tuning and demonstration of key technologies**
4. **Development and demonstration of operational techniques and processes for higher plant cultivation to achieve safe and high-quality food**
5. **Study of microbial behaviour and countermeasures within plant cultivation chambers**
6. **Actively advancing knowledge related to human spaceflight and transformation of research results into terrestrial applications**

Strategic expected achievements:

The proposed EDEN ISS project provides several benefits over the current state-of-the-art while advancing European technological competency by:

- improving the Technology Readiness Level (TRL) to 6 of key technologies for plant cultivation to be deployed in future BLSS,
- developing an ISPR cultivation system in preparation for future deployment on-board the ISS,
- manufacturing an in-situ plant production system to provide year-round fresh food supplementation for Neumayer Station III Antarctic crews,
- enhancing yield per production area while minimizing energy and resource requirements,
- utilizing the mobile test facility and its integrated subsystems to analyse the overall biomass production, resource use and crew time in a highly integrated plant production module,
- establishment of an international research partnership between Europe and Canada,
- leveraging the idea-to-market capacities by facilitating the interaction between space actors with non-space actors as well as SMEs in order to strengthen European competitiveness in this field,
- strengthening European research efforts within the BLSS domain while remaining complementary to present research initiatives (e.g. MELiSSA @ ESA, CAB @ ASI, FCU @ TAS-I, :envihab @ DLR).

Potential market areas for strengthening European competitiveness:

The following terrestrial markets and applications will benefit from EDEN ISS: full control of growth environment (increased resource efficiency), food quality and safety technologies and procedures, molecular farming and especially the present megatrend urban agriculture (e.g. vertical farming).

Consortium partners

Scientific Advisory Board

Dr. Wheeler (USA)

Prof. Dr. Giacomelli (USA)

Prof. Dr. Gunga (Germany)

Prof. Dr. Tikhomirov (Russia)

Prof. Dr. Kitaya (Japan)

Prof. Dr. Stefania De Pascale (Italy)

Top-level project background

Objective 1 - Manufacturing a space analogue mobile test facility

The first objective is the manufacturing of a space analogue mobile test facility for the provision of representative mass flows for the greenhouse key technologies (including secondary structures, interfaces, water-, thermal-, power-, and data lines).

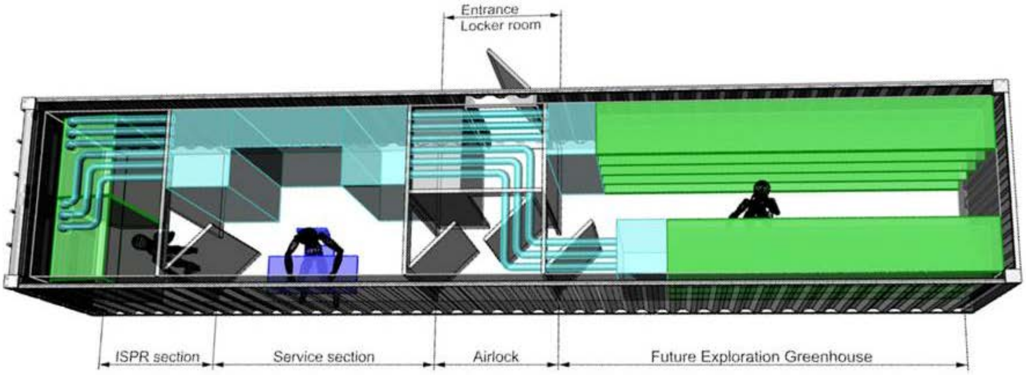


Figure 1: CAD drawing of one design option for the proposed mobile test facility

This way, a characteristic test environment can be created in order to establish high mission fidelity by offering space mission relevant aspects, including the planning of operations procedures and modes, deployment strategies, validation processes, plant handling operations, failure mode mitigation strategies, and experiments. Furthermore, human-machine interfaces can be tested with high accuracy. For the external structure of the facility, the project team proposes standard shipping containers to reduce the overall costs and to capitalize on already established logistics networks. Figure 1 shows a potential design of the interior of the mobile test facility, which will be split into three sections:

- **Service section** for the housing of subsystems providing necessary resources,
- **ISPR section** for integrated tests of ISS compatible systems,
- **Future Exploration Greenhouse** for testing CEA technologies for large-scale production systems.

Combining the ISPR section and the Future Exploration Greenhouse (FEG) together with the service section will allow the consortium partners to test detailed food production procedures including plant health monitoring, microbial detection/decontamination and food safety – all aspects imperative to future space mission scenarios implementing BLSS.

Objective 2 – Integration of key technologies in an ISPR-like system and in a Future Exploration Greenhouse

The **ISPR section** will offer two full ISPR cultivation systems, which will house all necessary support systems for the successful cultivation of higher plants. When integrated into the main supply lines of the mobile test facility, a close similarity towards the deployment on-board ISS will be accomplished. Putting the necessary CEA technologies into the geometric constraints of the ISPR will result in the optimization of all accommodation parameters. Technologies like highly integrated plant accommodation, volatile organic compounds (VOC) separation, nutrient delivery system, plant health monitoring sensors, and highly reliable bio-detection and decontamination will be investigated. Particular attention will be given to the contamination control system in order to minimize cross-contamination with respect to the surrounding environment. This will further push the development boundaries for safe on-orbit food production. The ISPR section allows the project team to test essential planting-, maintenance-, and harvest procedures applicable for a potential ISS deployment. Indeed, a 1 m^2 production area is possible through the employment of such a rack-based system incorporating rapidly maturing CEA technologies. Not considering the planned VEGGIE and

Advanced Plant Habitat facilities, the full ISPR cultivation system developed as part of EDEN ISS will provide at least an order of magnitude increase in production area over past systems (Figure 2).

The **FEG** will offer a unique test environment to conduct innovative plant production methods necessary for future planetary missions to Moon and Mars. Technologies that can be deployed are ion-selective sensors, intra-canopy lighting, and low-energy water recovery systems. While the greenhouse chambers within the ISPR section only produce small quantities of edible biomass (as dietary supplement), the FEG will offer larger quantities and wider variety of crops for the crew. This is important in order to investigate the different psychological aspects that higher plants have on isolated crews, while ensuring that the mobile test facility provides a relevant contribution to the overwintering crew's diet. Handling and operations procedures can also be tested within the FEG on a larger scale (e.g. telepresence, plant cultivation protocols, crew time).

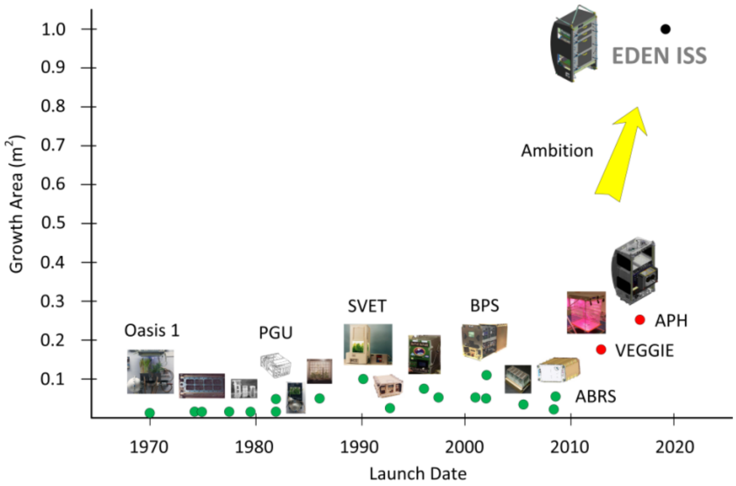
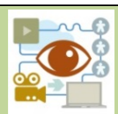


Figure 2: Plant growth area plotted versus initial launch date for the bulk of crewed vehicle plant growth experiment payloads. Past and present facilities indicated in green. Currently planned facilities indicated in red.

This **dual approach**, allows the project team to investigate essential aspects of future BLSS, utilizing higher plants and to pin-point critical technology areas to be tested on the ISS as a preparatory step for future exploration missions.

Objective 3 - Adaptation, integration, fine-tuning and demonstration of key technologies



The consortium will **demonstrate selected key technologies**, which have relevancy to every greenhouse, whether space or terrestrial. The technologies selected for demonstration include:

- Nutrient delivery system,
- High-performance LED lighting system,
- Bio-detection and decontamination system,
- Food quality and safety.

The systems will first be assembled and separately **tested under laboratory conditions** to ensure their functionality and to assess resource requirements. Afterwards, all systems will be integrated into the mobile test facility and an overall system test performed. During this test several plant cultivation cycles will be executed and the systems fine-tuned to ensure optimal functionality. Passing this test, the mobile test facility will be cleaned, sterilized and sealed for transportation to the analogue test site.

Figure 3: Neumayer III Antarctic research station operated by the AWI

The analogue test site for the proposed project is the Neumayer III Antarctic station of the Alfred Wegener Institute for Polar and Marine Research (AWI), see Figure 3. The Neumayer III station is selected for the location of the mobile test facility, because of its logistical, infrastructural and environmental properties. The crew size and composition during winter is also similar to a crewed spacecraft. The winter period, with duration of 9 to 10 months, is foreseen for the validation of the systems, because of the high space mission fidelity. The **long-duration of the test campaign** allows several cultivation cycles of plants and therefore several possibilities for testing various system settings and operational modes.

Objective 4 – Operation techniques for higher plant cultivation to achieve reliable and safe production of high-quality food

Any system failure in BLSS could result in a catastrophic event culminating with mission abort or, even worse, loss of crew. EDEN ISS will implement, in addition to the nominal **greenhouse environmental control loop**, a parallel 'control loop' based upon the support of experts composed of plant biologists, microbiologists, horticulturalists and engineers to prevent such operational issues. These experts will utilize the greenhouse monitoring systems and telemetric data and with the help of the crew identify at an early stage, any possible problems/diseases of the crop and solve/isolate/mitigate them to ensure the proper functioning of the greenhouse.

The first subcategory is the operations procedures, which are important for optimal plant cultivation in order to achieve maximum biomass output, but also to prevent biological or non-biological (cross-) contamination. The **necessary handling procedures** for all plant lifecycle phases (e.g. germination-, juvenile -, and generative phase) dealing with the ISPR system and the FEG will be investigated. Furthermore, proper post-harvest procedures need to be developed in order to guarantee the required quality standards for consuming the crops. Sterilization procedures are also important in order to increase the shelf life of the harvested crops. Similar procedures were investigated during NASA's analogue test campaign with the Habitat Demonstration Unit in 2009. The project team will build on these findings and will further expand the knowledge in this critical field.

The second subcategory is dedicated to **food quality and safety**, which are essential for long-duration space missions. If crops are cultivated for food purposes, adequate procedures need to be implemented in the production cycle. Crops, harvested within the ISPR systems and the FEG will be subject to intensive testing by investigating new safety- and quality technologies (e.g. quick food safety tests, new sanitizing procedures, innovative packaging technologies for long storage and preservation capability).

Objective 5 - Microbiological behaviour and countermeasures in plant-based closed ecosystems

The **microbial diversity and dynamics** in facilities with plant and human interaction will be addressed through a number of experiments conducted in parallel to the technical test and fine-tuning campaign at the Antarctic test site. The high humidity and the high temperatures inside the mobile test facility provide a favourable environment for the growth of various microorganisms (e.g. bacteria and fungi), known to compromise human health, as well as the spoilage of the produced food, water, and air and the deterioration of materials (e.g. bio-corrosion). Microbiological samples will be taken at regular intervals before and during the test campaigns from various locations within the mobile test facility.

Objective 6 - Advancing knowledge related to human spaceflight and transformation of research results into terrestrial applications

The sixth objective addresses the **identification of possible spin-offs into terrestrial applications** to the benefits of European citizens. The cutting-edge technologies that will be developed during the project to reduce resource requirements will enrich the present knowledge of sustainable greenhouse production. Closed or nearly closed-loop plant cultivation systems can enable terrestrial agriculture to be conducted in areas that are currently unsuitable. Additionally, innovative lighting systems will extend European greenhouse growing seasons and permit plant growth in structures such as abandoned industrial buildings (e.g. urban agriculture, vertical farming) where natural light would otherwise be insufficient. The knowledge, which will be acquired about the effect of growth environment on food quality and the content of specific compounds, has obvious potential for terrestrial applications.