THE EDEN INITIATIVE AT THE GERMAN AEROSPACE CENTER (DLR)

Achievements, Vision, & Progress through Innovation and Collaboration

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10.03.2025

Planetary Infrastructures,
Institute of Space Systems

International Workshop on Space Agriculture and Horticulture, Chiba University

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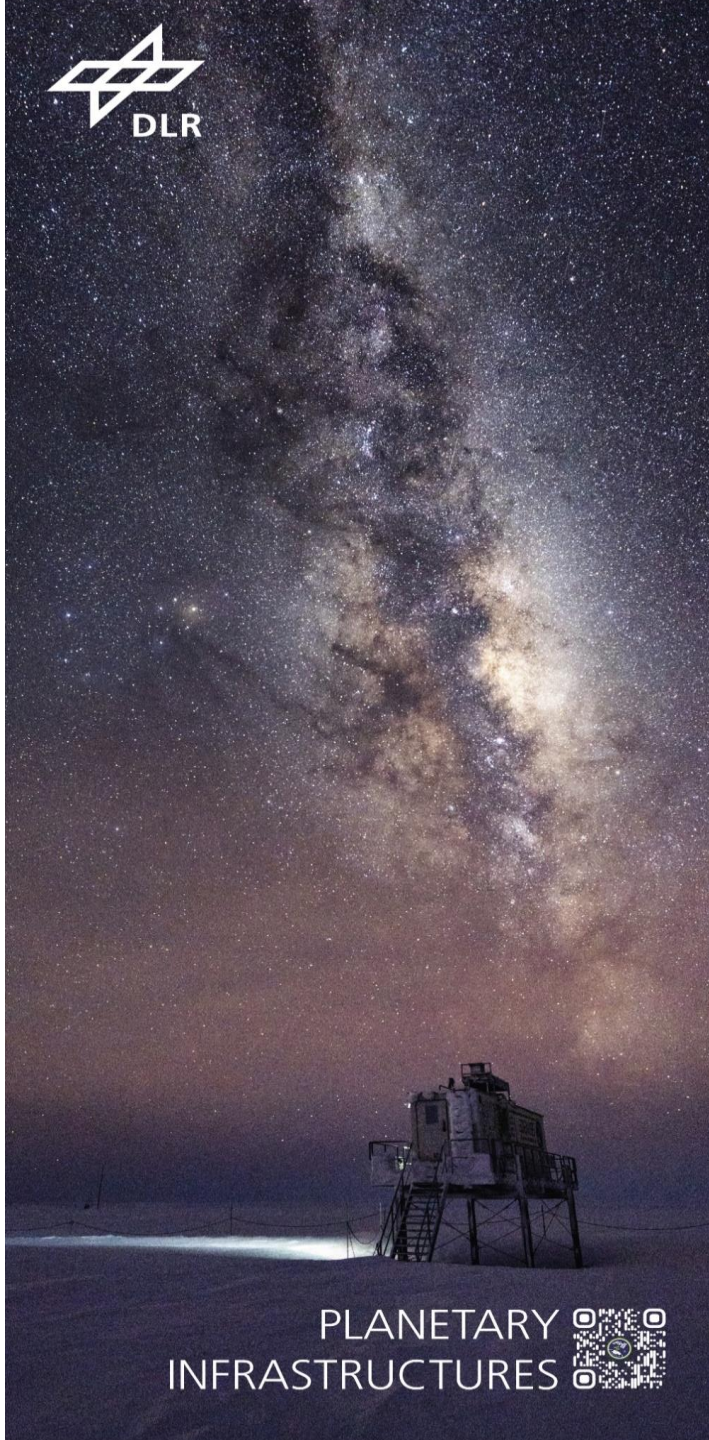
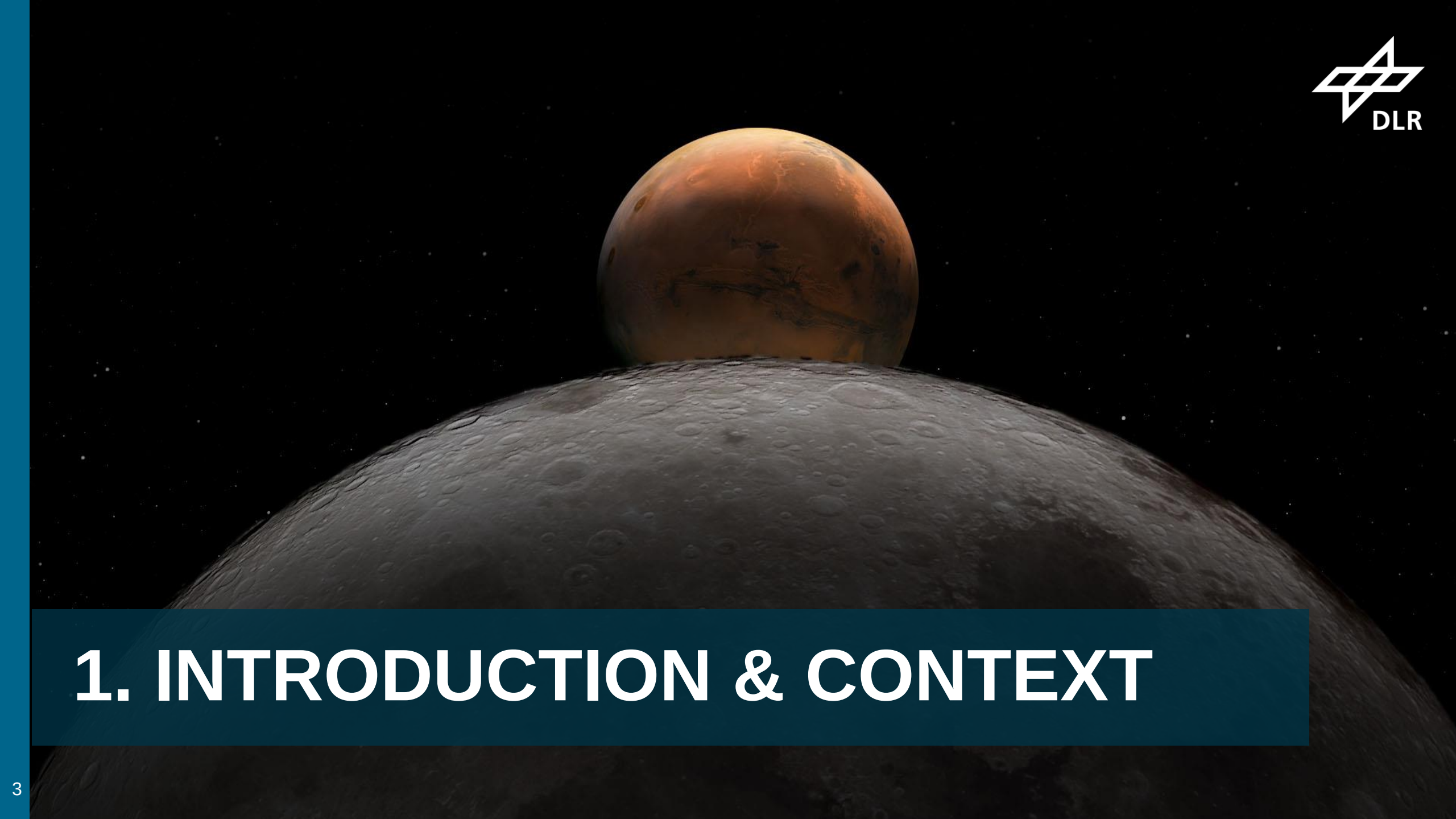
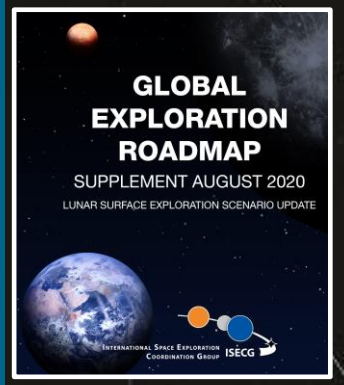




1. INTRODUCTION & CONTEXT



International Space Exploration Coordination Group (ISECG) and its coordinated efforts in space exploration of the Moon and Mars

&

ARTEMIS

ORBITERS
ROVERS
LANDERS

ARTEMIS
(2010)

LRO
(2009)

ORION
SPACECRAFT
2020

POWER &
PROPULSION
ELEMENT
2022

ORION CREWED
EXPLORATION

GATEWAY IN
LUNAR ORBIT
2026

ISS–SUSTAINABLE
LOW-EARTH
CAPABILITY
2000 –

SMALL COMMERCIAL
LANDERS
2019 –

MID-SIZE ROBOTIC
LANDERS
2022

ADVANCED
EXPLORATION LANDER
2026

2018

2022

2026

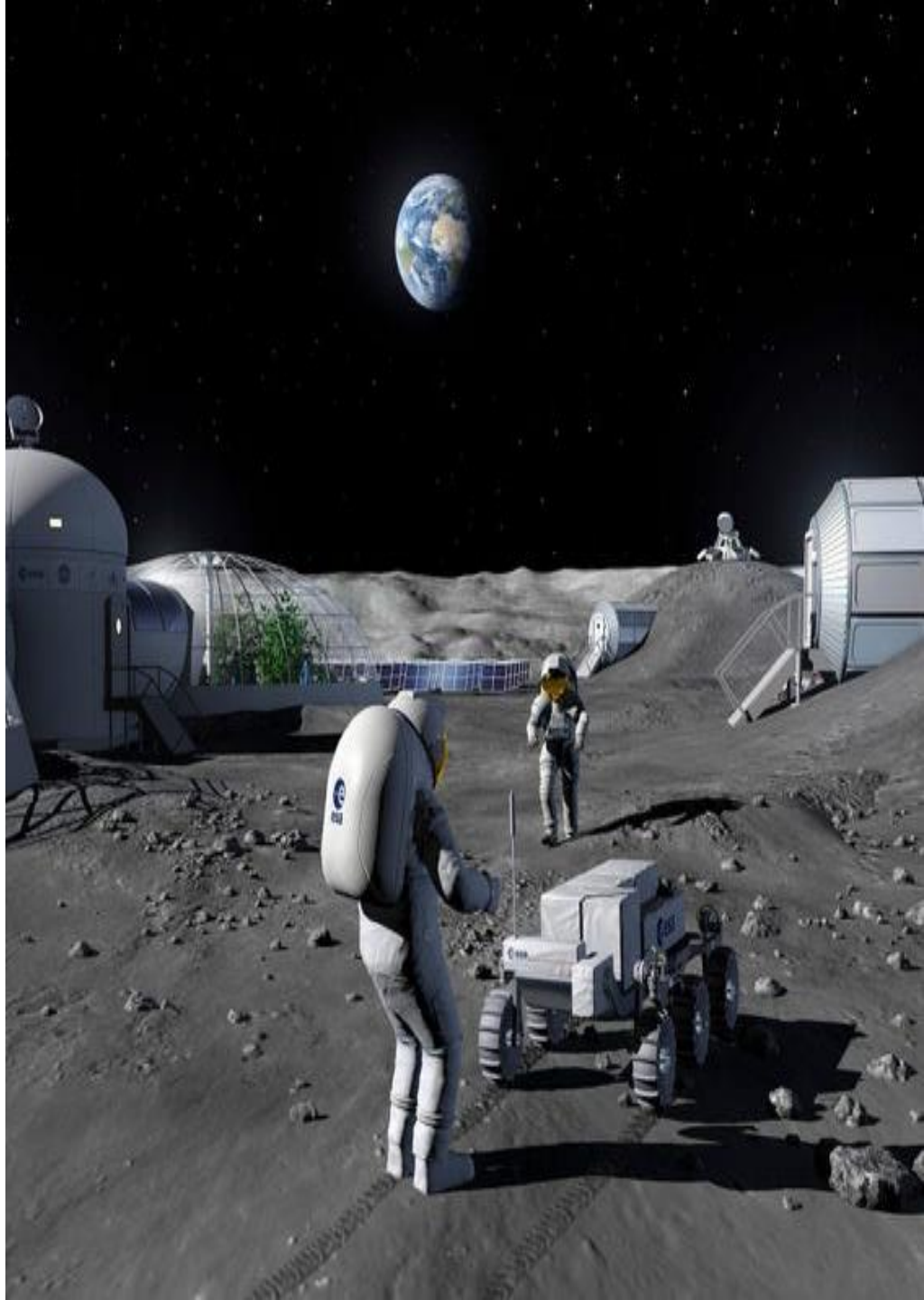
20181129

WHY ‘Space Agriculture’ ?

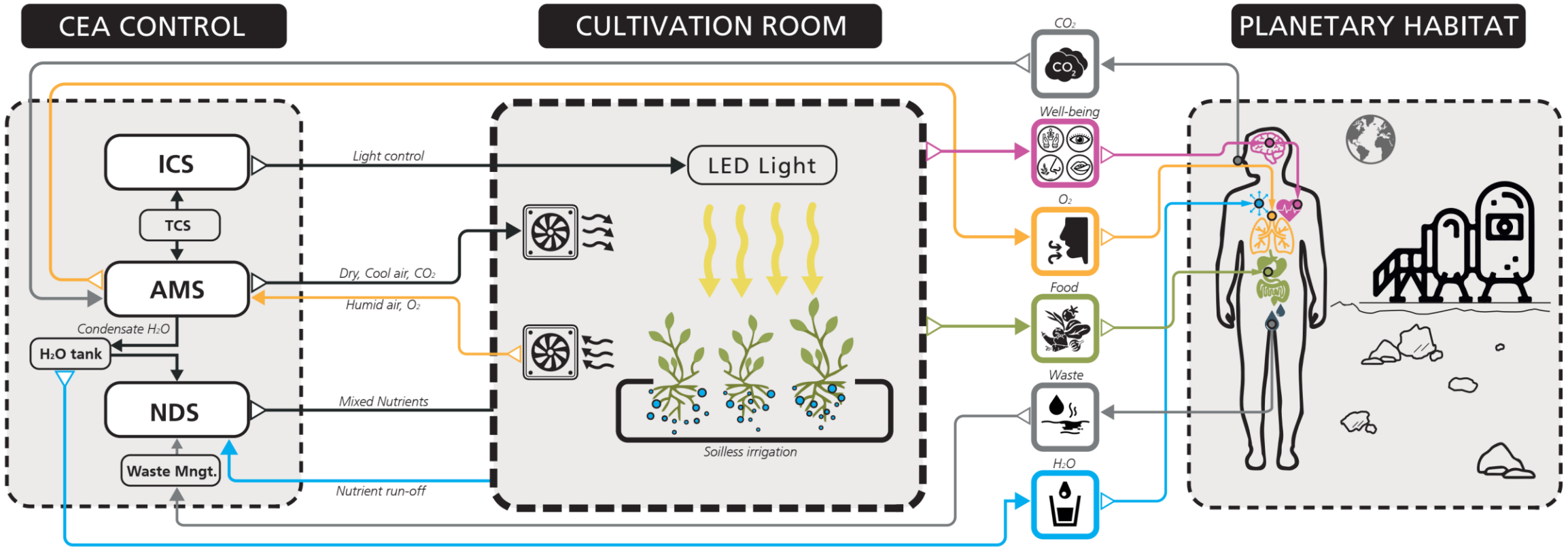
Space Agriculture / Bioregenerative life support system (BLSS) is essential for…

- ❖ the stable and sustainable execution of long-duration human spaceflight missions
- ❖ reducing dependence on Earth‘s resources during interplanetary missions

- **Food Support:** rely on prepackaged foods for ISS ⟶ logistical & financial constraints for Lunar/Martian mission
- **Life System Support:** O2 generation, CO2 removal, Water recycling
- **Crew Well-Being** (Psychological Benefits)
- **Innovative Agriculture Technologies:** Adapting to climate change effects on food production



ALL-IN-ONE APPROACH FOR BLSS



- Controlled Environment Agriculture (CEA) Technologies
- Fresh food, CO2 fixation, O2 generation, water recycling, waste mgmt., well-being
- Necessity to fully integrate CEA technologies into one lightweight space system!

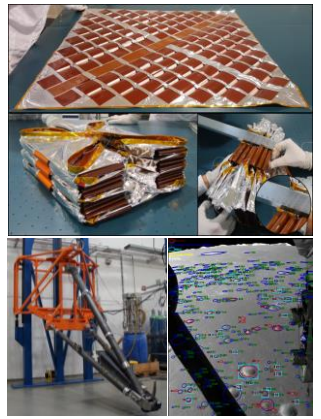
NDS: Nutrient Delivery System **AMS:** Atmosphere Management System **ICS:** Illumination Control System

DLR IN BREMEN

System Development

- MASCOT Asteroid Lander, Landing in October 2018 on Ryugu
- CompactSat Eu:CROPIS, launched December 2018
- HP³ instrument of InSight, landing 2019 on Mars, cooperation with NASA/JPL
- CALLISTO, reusability flight demonstrator, CNES/JAXA/DLR cooperation, test flights in 2025
- **EDEN-ISS, Green house demonstrator, analogue testing in Antarctica 2020 – 2022**
- MMX rover for landing on Phobos,cooperation with JAXA,CNES
- Etc…

Enabling Technologies



- Core Avionics & GNC
- Cryogenic Propellant Management
- Landing Technololgies
- Deployable Membranes

Advanced Methods

- Concurrent Engineering for Concept Phase (CEF)
- Digital Spacecraft, Model Based System Engineering
- Digital Space Lab (Integration)
- Automated design and verification of avionics and GNC

More info.: https://www.dlr.de/en/irs/about-us/departments

PLANETARY INFRASTRUCTURES (Former EDEN Initiative)

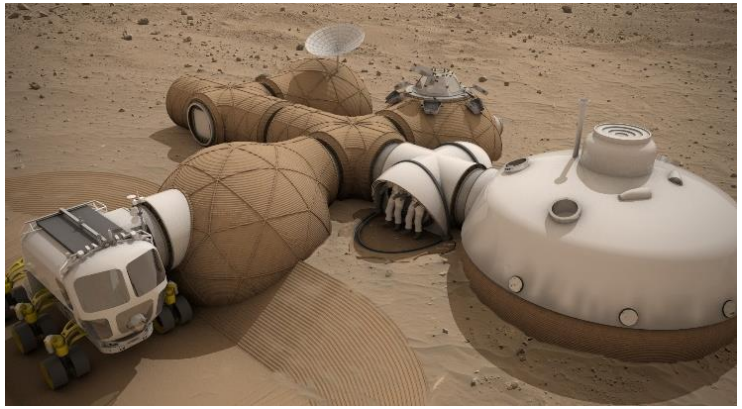
Research group since 2011 @ Institute of Space Systems

Bioregenerative Life Support System (Plant Cultivation Sys.)

In-situ Resource Utilization

(Since 2021, Synergetic Resource Utilization (S.M.U) Team)

Habitat Infrastructure Design



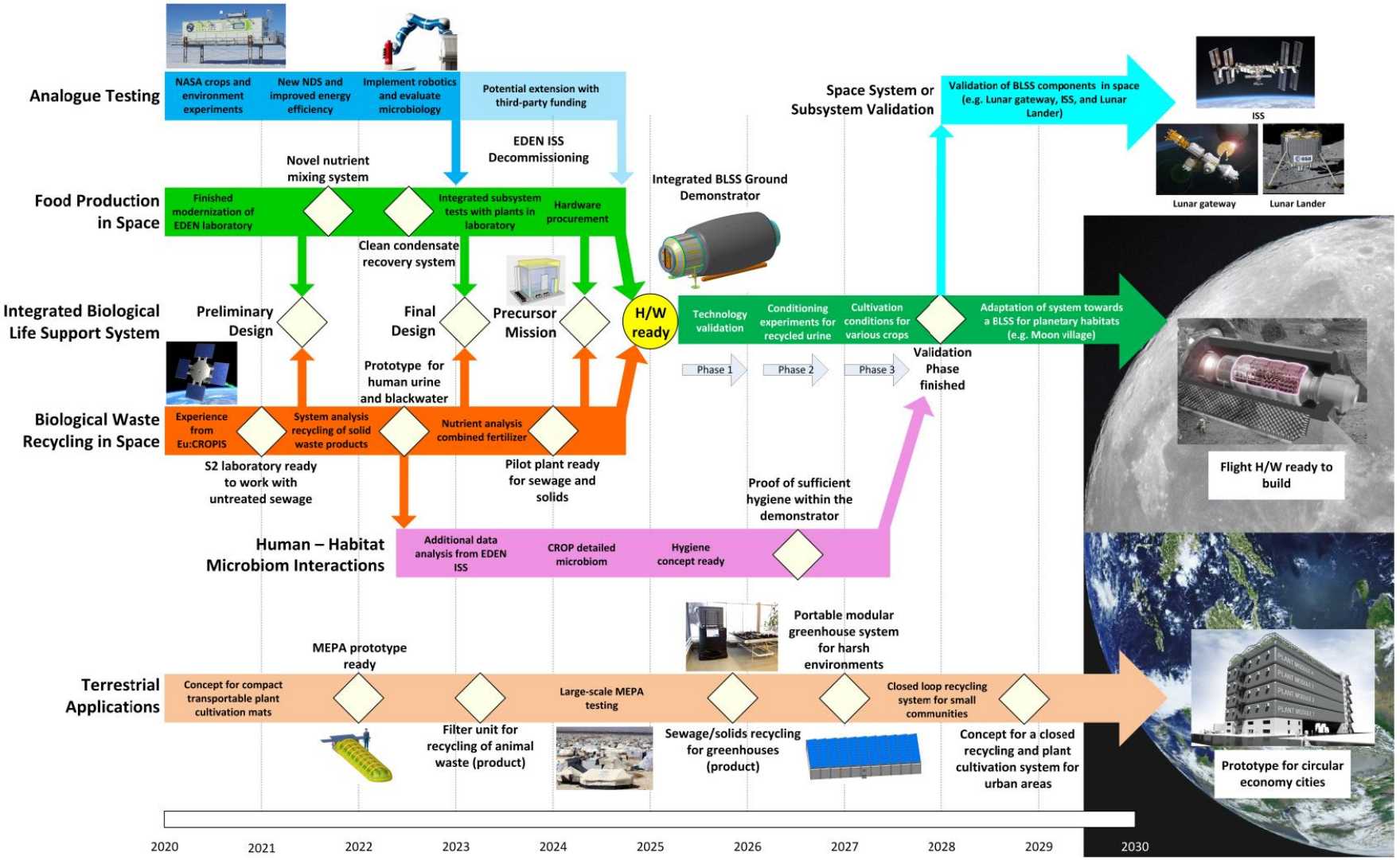
Research & Development Objectives

- Technology Hardware Developments
- System Analysis on Habitat Integrations
- Analogue Field Testing
- Technology Transfer

DLR ROADMAP (2020-2030)

DLR Roadmap (Released in 2020)

- R&D of a Ground Test Demonstrator (GTD) by ~2026
- 2030: Space-ready design of an integrated greenhouse system for Lunar surface
- Transition to industry for hardware build-up



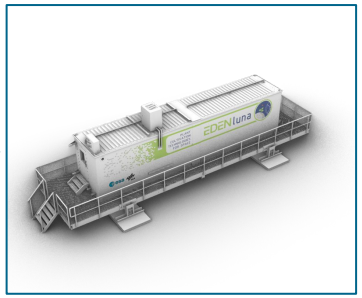
DEVELOPMENT PATHWAY OF BLSS FOR LUNAR MISSION

Laboratory Testing

- CEA breadboards
- Functional principles

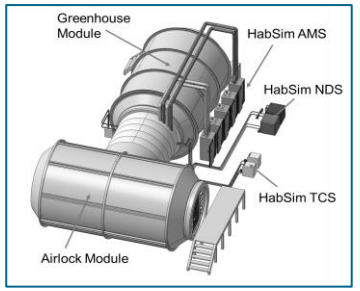
Analogue Testing I

- Integrated system, but COTS parts
- Still breadboard level
- Extreme environment



Testing II

- COTS base
- Advanced CEA (Robotic, waste management, nutrient generation)



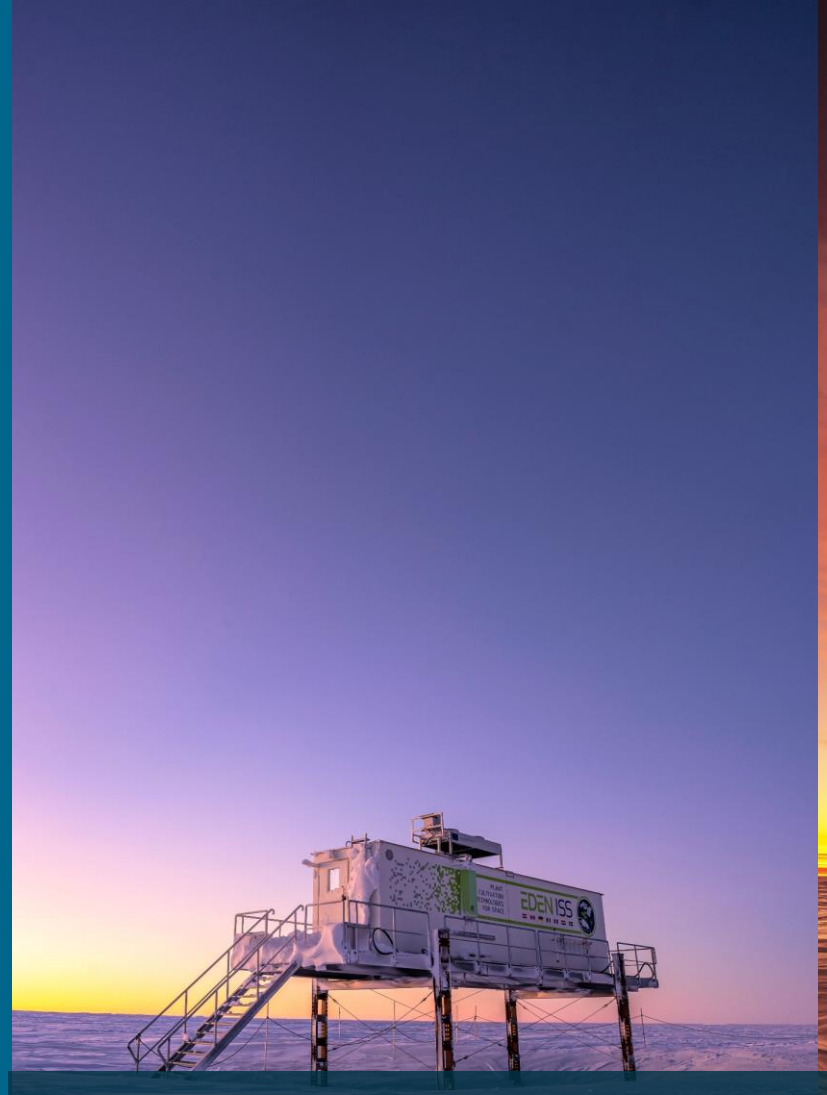
Ground Testbed

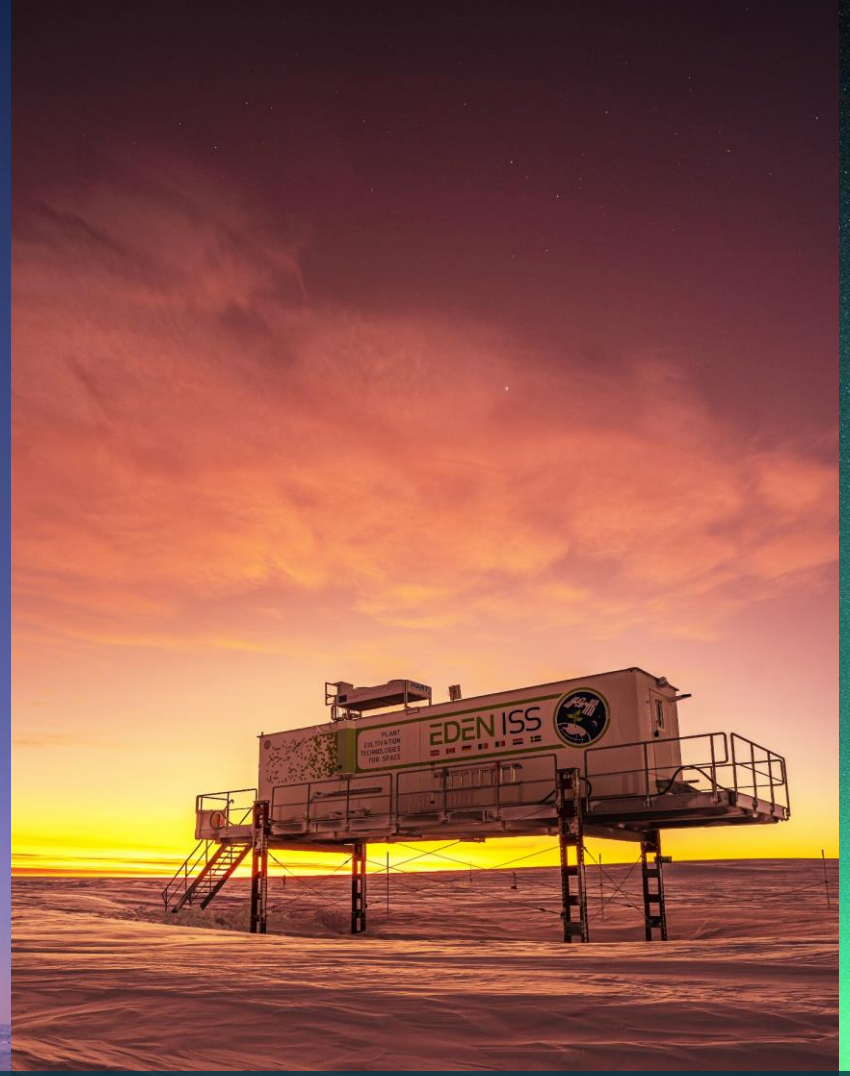
- Space-ready system
- Full redundancy & S/S accommodation

Space Deployment

- Full space flight system
- Bio-regenerative Life Support System

- Increasing the TRL of Lunar Agriculture Module
- Final goal is a full-size life support module for human exploration purposes

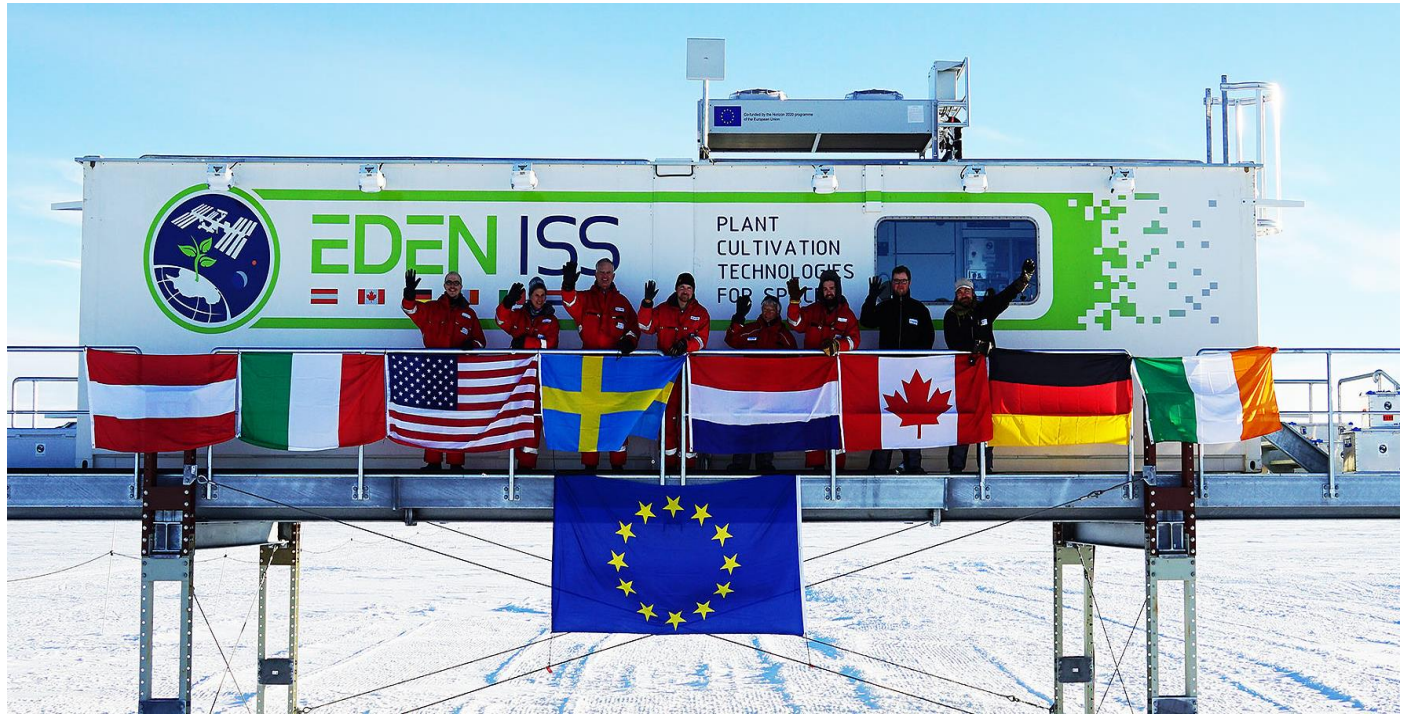




2. ACHIEVEMENTS: EDEN ISS

EDEN ISS

- H2020 Project (~5M€)
- 14 partners from industry, universities, research institutes
- 8 countries
- Start: 2015 End: 2019 (Now: DLR)
- First complex greenhouse analogue mission to Antarctica – German Neumayer Station III (AWI)



EDEN ISS

Partners

DLR · ThalesAlenia Space · University of Guelph · Liquifer Systems Group · Airbus Defence & Space · heliospectra · ENGINSOFT · UF University of Florida · ARESCOSMO Defence and Space · Consiglio Nazionale delle Ricerche · AWI · Wageningen University · Limerick Institute of Technology · Telespazio

EDEN ISS

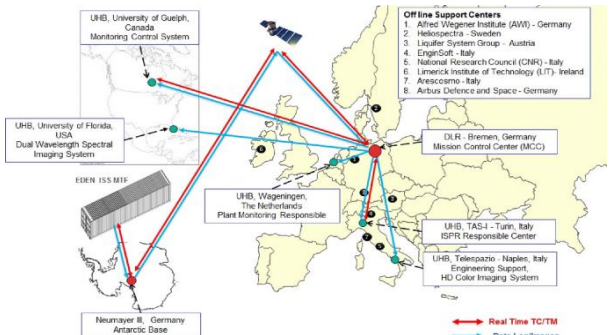
- NASA/DLR Joint Analogue Mission 2021

<H2020>

- Initial Deployment Mission 2017/2018
- Main Analogue Mission 2018

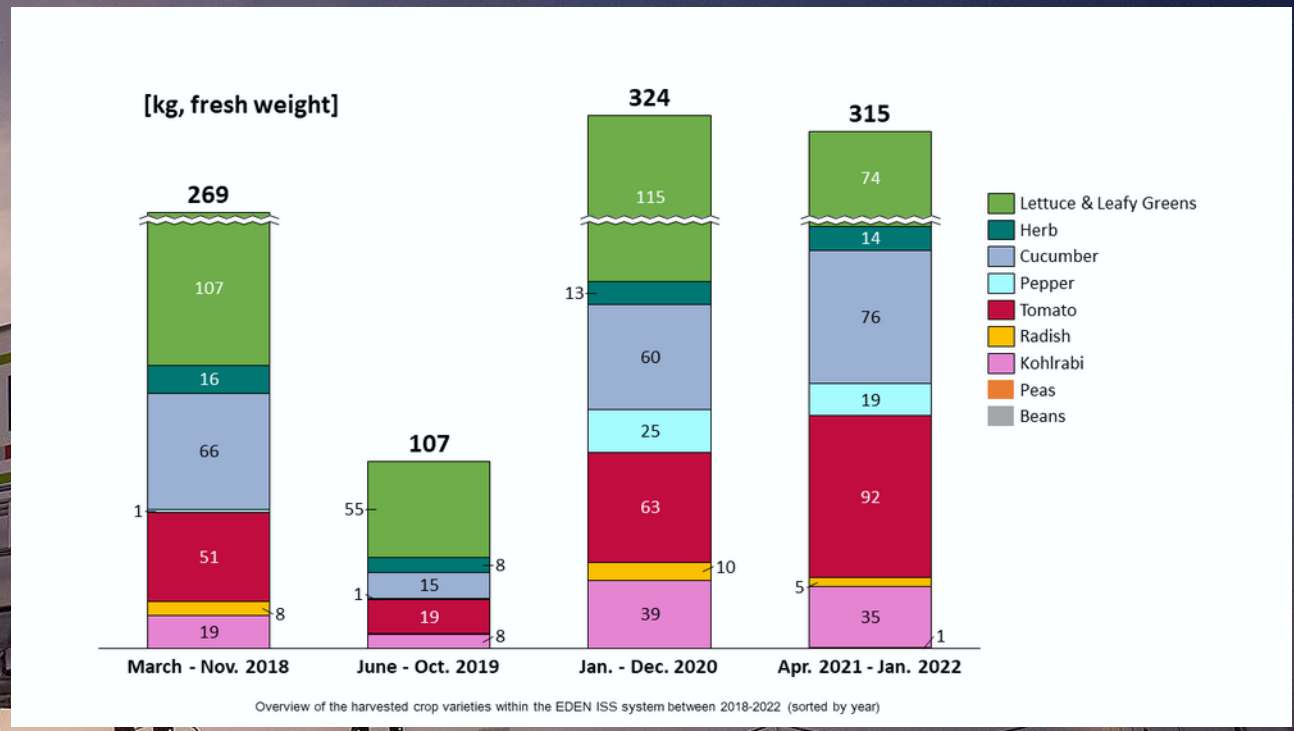
- Delta Mission 2019 (DLR/AWI)
- Delta Mission 2020 (DLR/AWI)

- Test of critical cultivation technologies in extreme environment
- Humans-in-the-loop investigations, microbial investigations, crop selection, etc.
- Controlled by Mission Control Center (MCC) in DLR Bremen
- Significant public outreach and spin-off project



PRODUCTION RESULTS

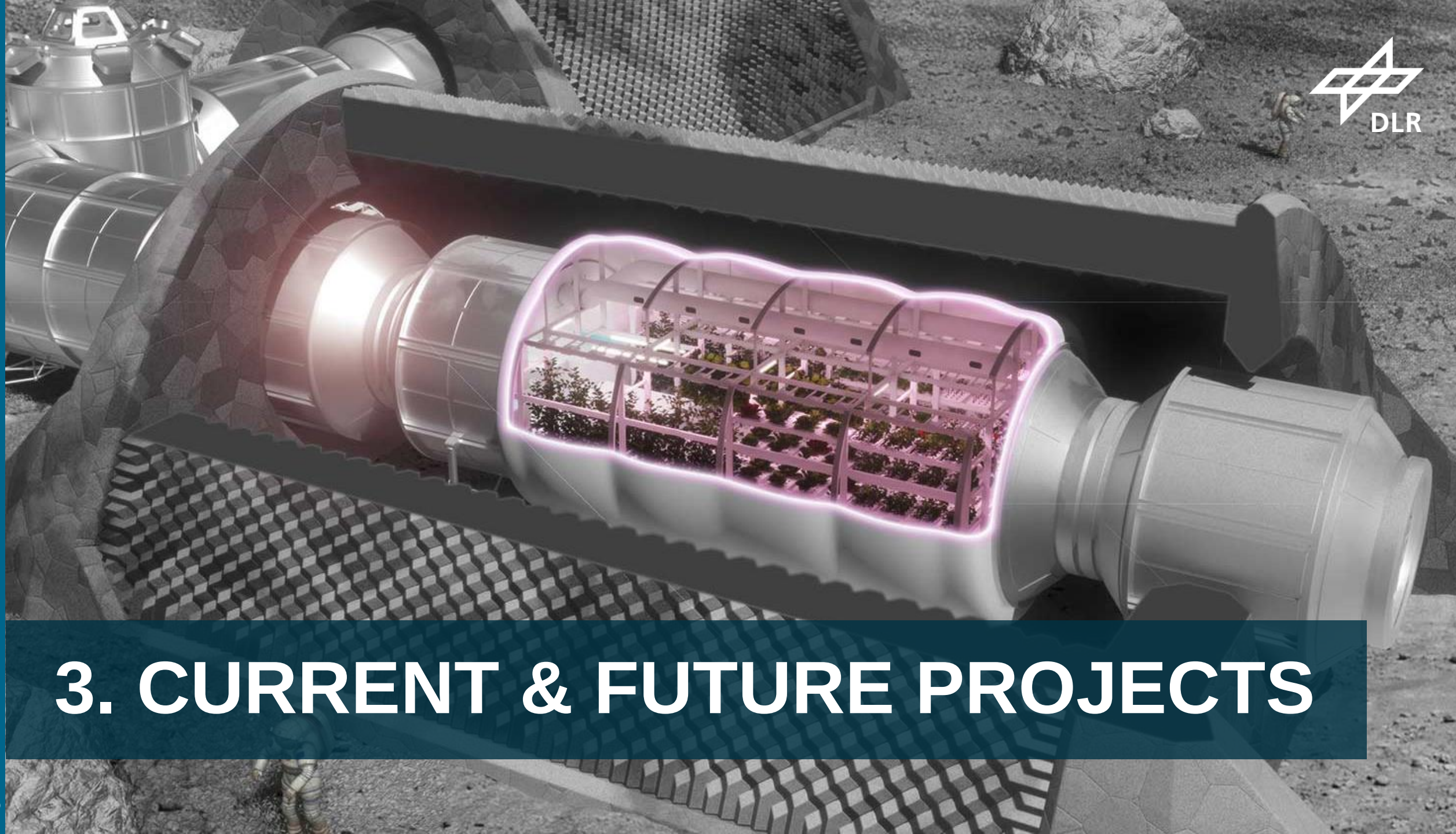
- 5 years of analogue testing at the German Research Station Neumayer III in Antarctica
- Stepping Stone towards long-duration & permanent Human Outposts on Moon/Mars
- **Over 1000 kg** of fresh crop production during missions



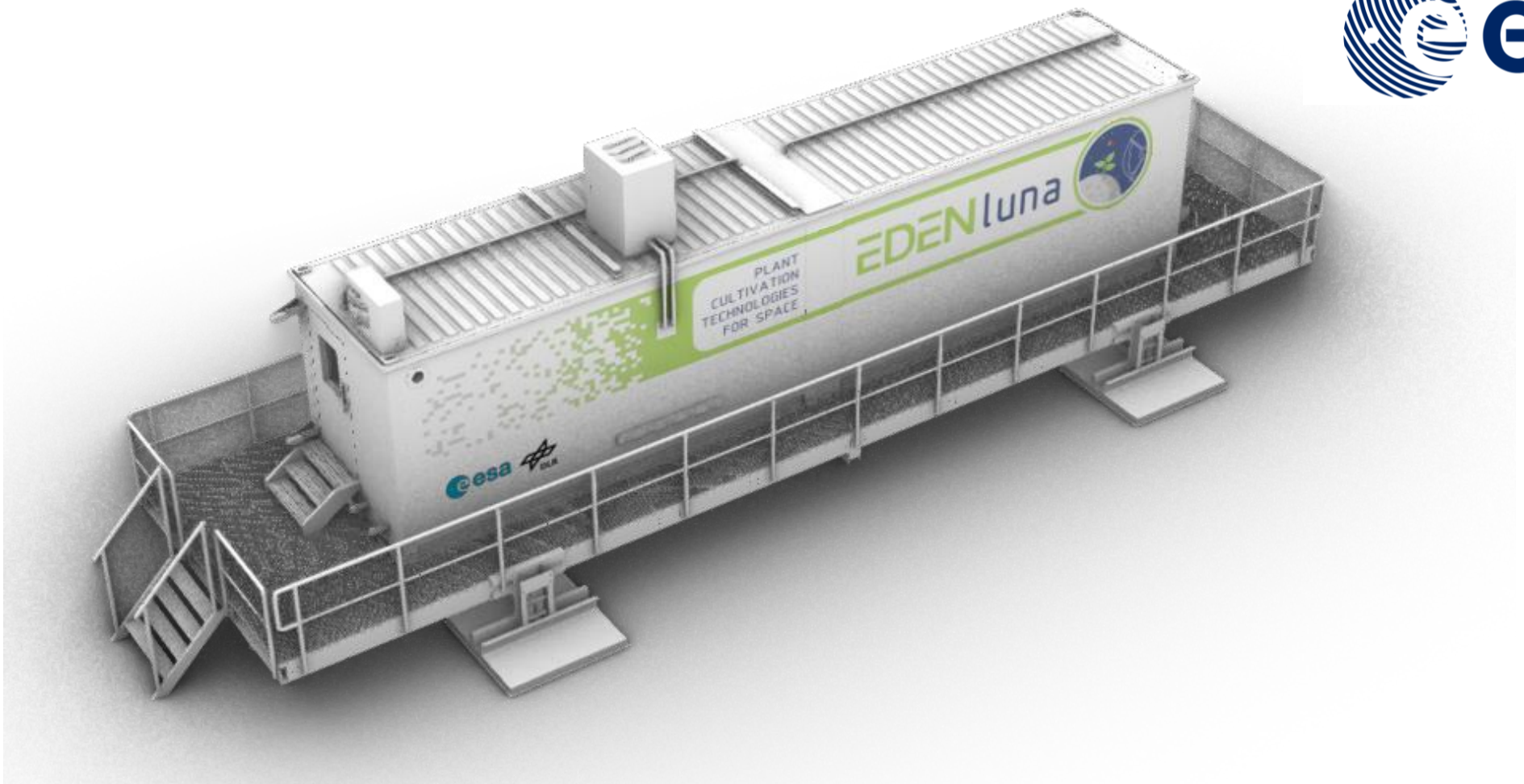
Overview of the harvested crop varieties within the EDEN ISS system between 2018-2022 (sorted by year)

LESSONS LEARNED

Category	Key Points
Thermal & Energy Efficiency	• LED lighting waste heat maintained greenhouse temperatures even in -40°C external conditions (**supplemental heating** needed in **service areas**) • Approximately 10 kW **power consumption optimized** by adjusting lighting schedules and environmental controls
Crop Cultivation Challenges	• **Nutrient solution formulations required periodic adjustments** due to water quality changes and species-specific responses • Developed **crop-specific cultivation protocols** to optimize yield and quality
System Reliability & Maintenance	• **Redesigns** were necessary for the **water recovery/purification system** • **Improved filtration and maintenance protocols** addressed clogging issues in the aeroponic misting system
Human Factors & Psychological Benefits	• Initial operator **workload of 3–4 hours daily was reduced** through automation and refined procedures • **Practical, hands-on training** enabled non-botanists to effectively operate the system • Access to fresh vegetables and the greenhouse environment **boosted crew well-being** during isolation
Future Directions	• Planned enhancements include increased automation, improved energy efficiency, compact designs, and advanced remote monitoring • Research into integrating regenerative life support (e.g., converting crew waste to plant nutrients) and optimizing systems for partial gravity (Moon/Mars)



3. CURRENT & FUTURE PROJECTS



3.1 EDEN LUNA

EDEN LUNA

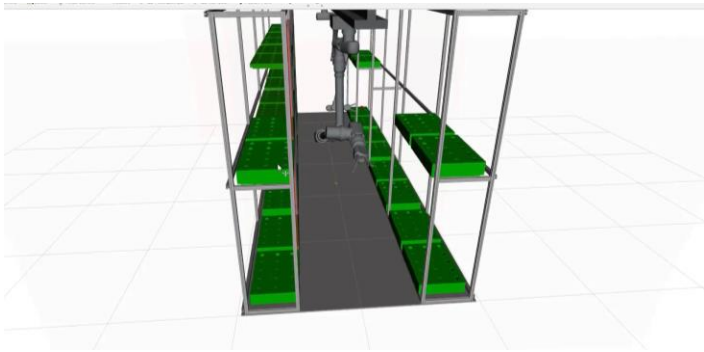
Unique TEST BED

- Co-financed by NRW
- Upgrade of existing systems
- Astronauts-in-the-Loop testing
- Mission Control by DLR-RY
- Preparatory step for EDEN Next Gen.

Key Features (DLR Institutes)

- DLR-RY: Full Controlled Environment Agriculture (CEA) integration
- DLR-RM: AI - robotic assistance
- DLR-ME: Urine processing => water recovery
- DLR-DW: Risk Mitigation applications
- Other DLR Institutes might join as well

CEA Technologies



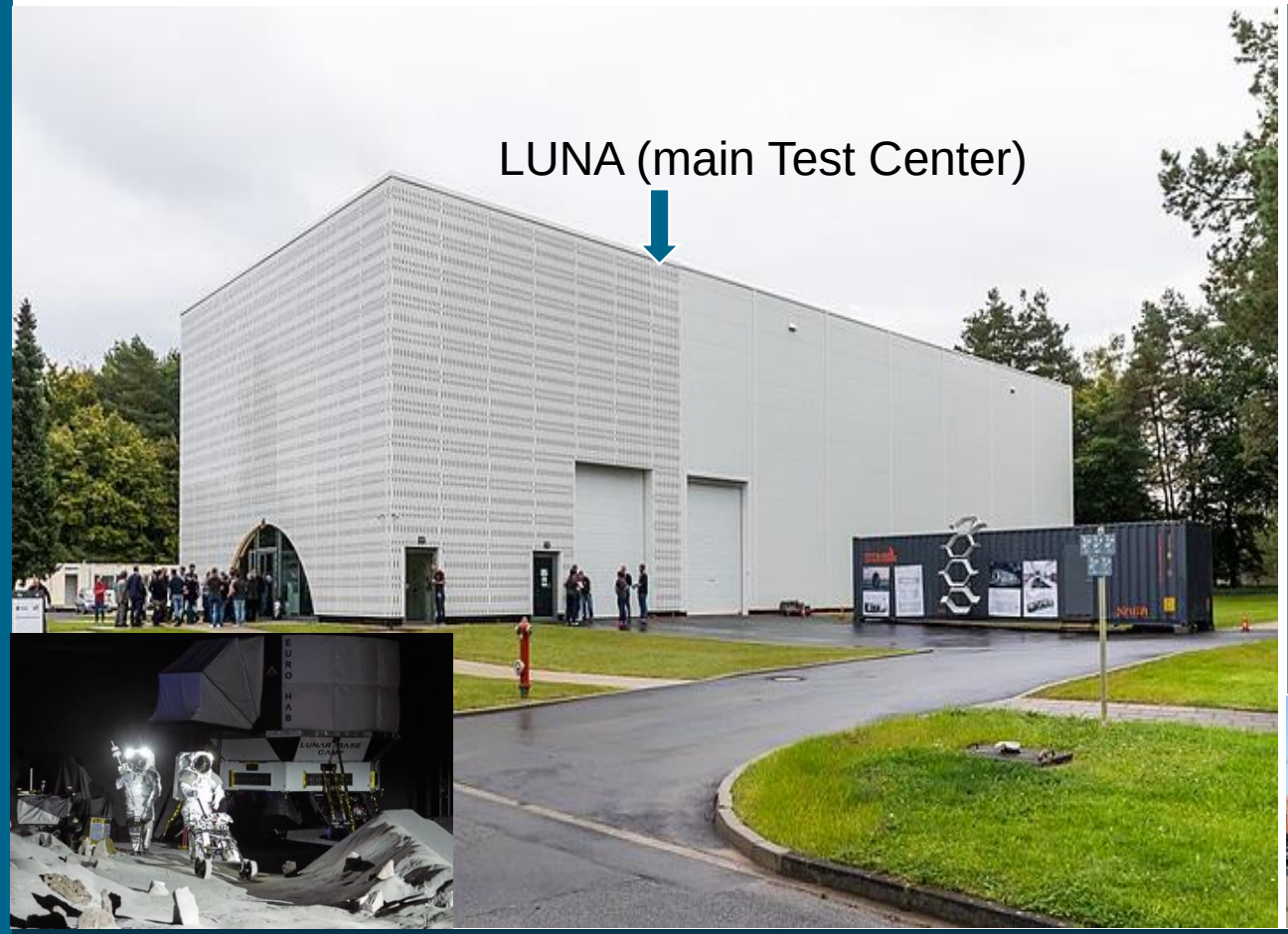
AI-Robot System

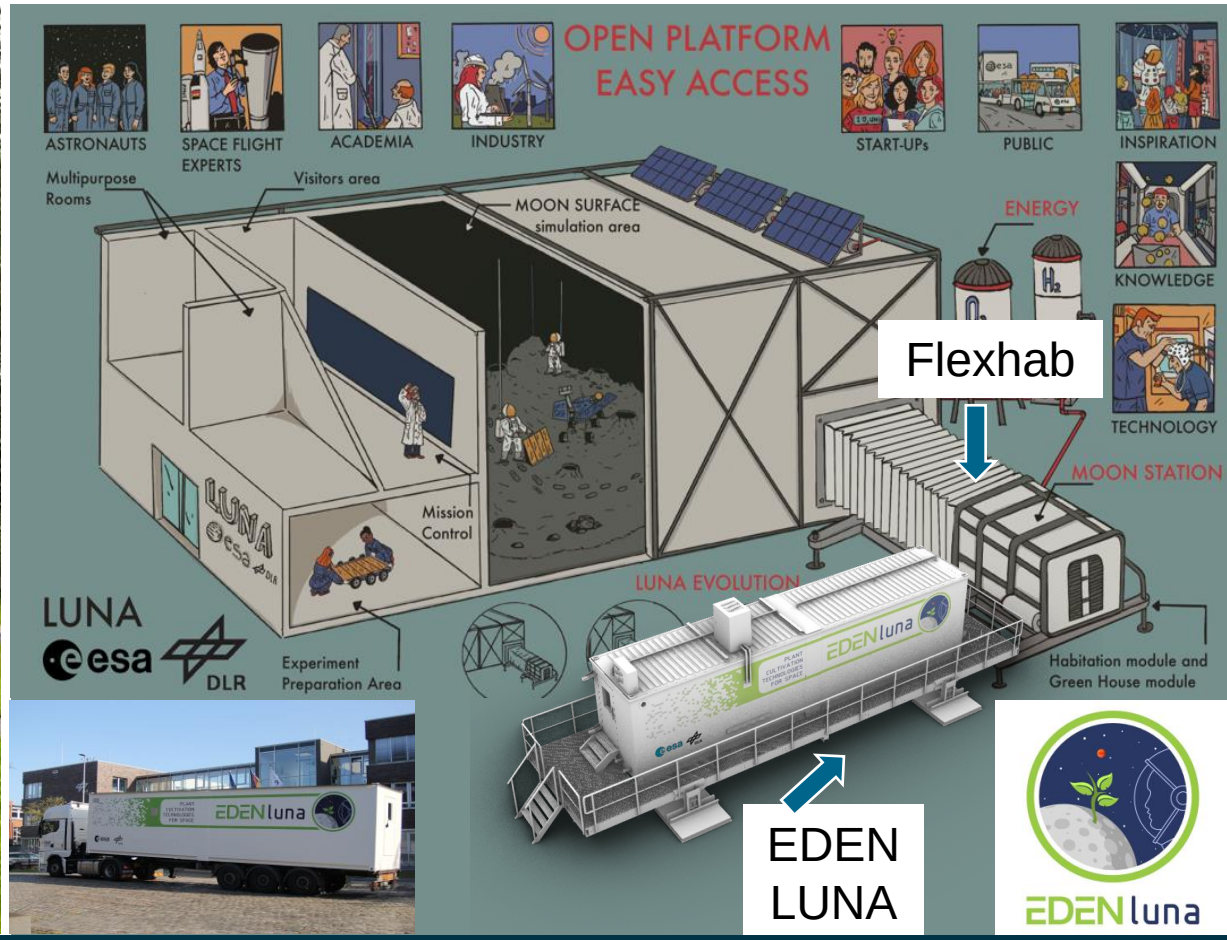
C.R.O.P. Urine Filters

Risk Mitigation

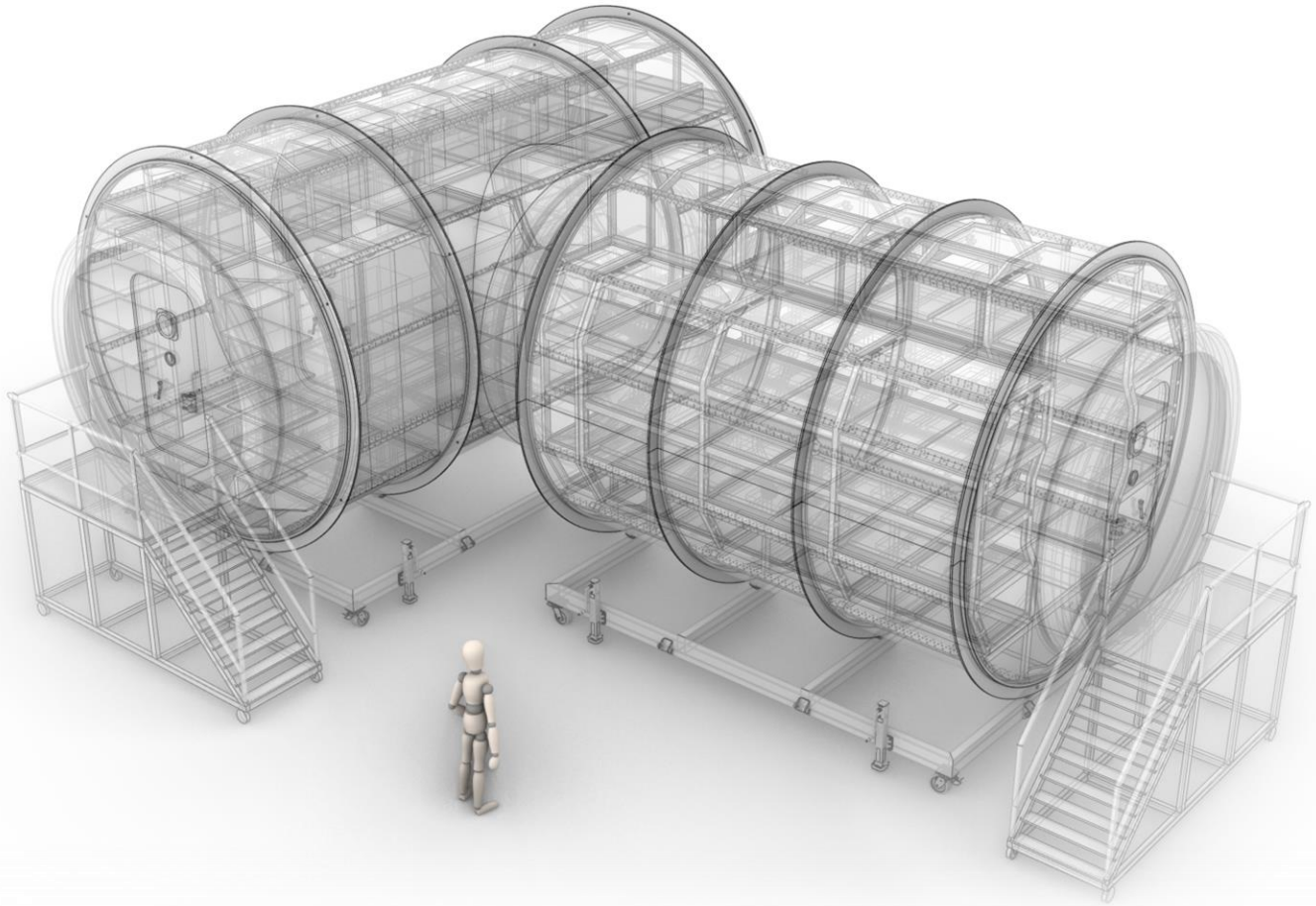
Advance EDEN Analogue for CEA technologies by extending the prototype with new robotic, waste management and nutrient generation (C.R.O.P.) elements to support a highly autonomous bio-regenerative Life support system on Breadboard Level.

EDEN LUNA





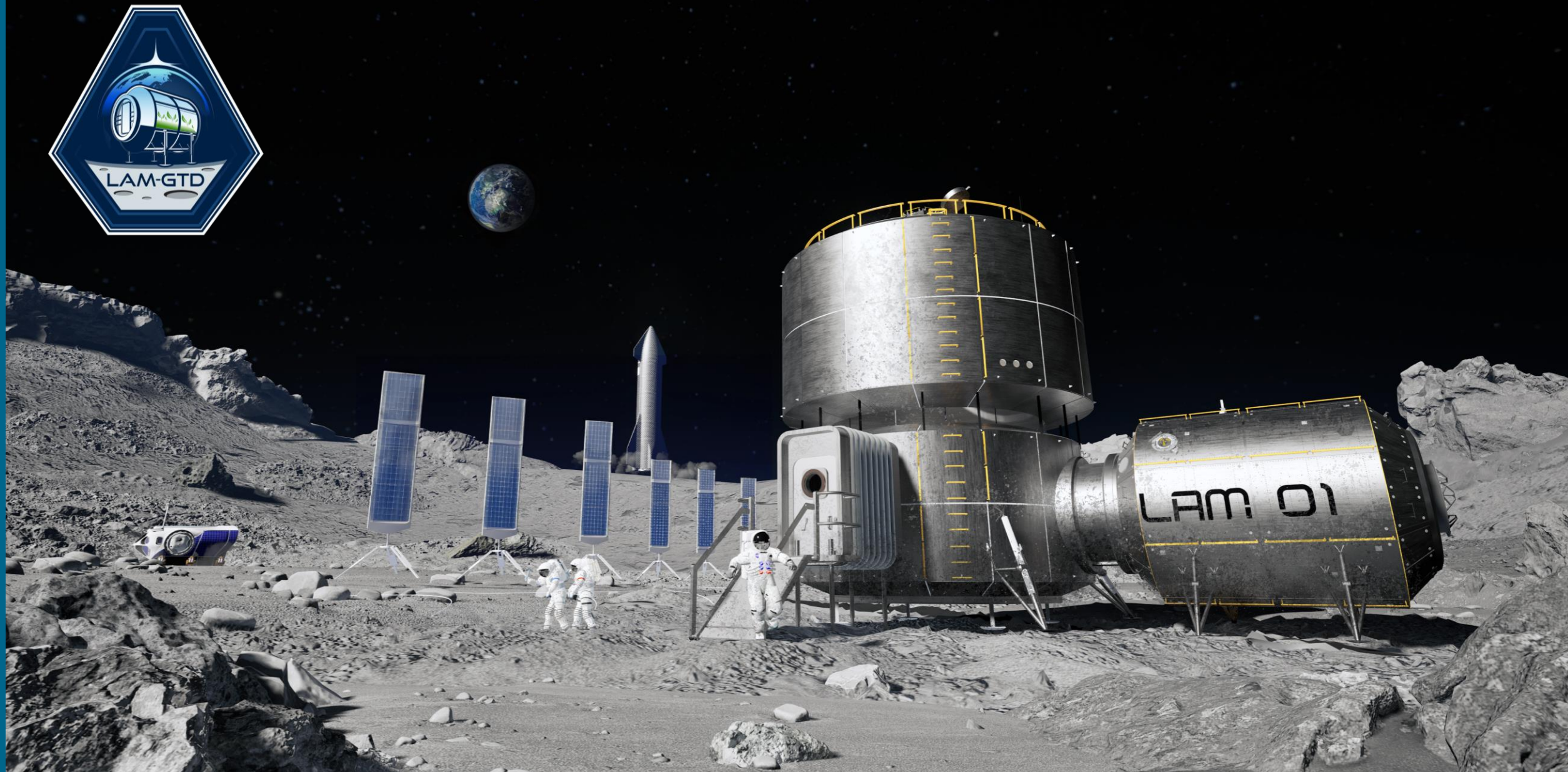
- Part of the LUNA Analogue Facility – DLR Collaboration with ESA
- Refurbishment and improvement of the EDEN ISS Antarctic Greenhouse



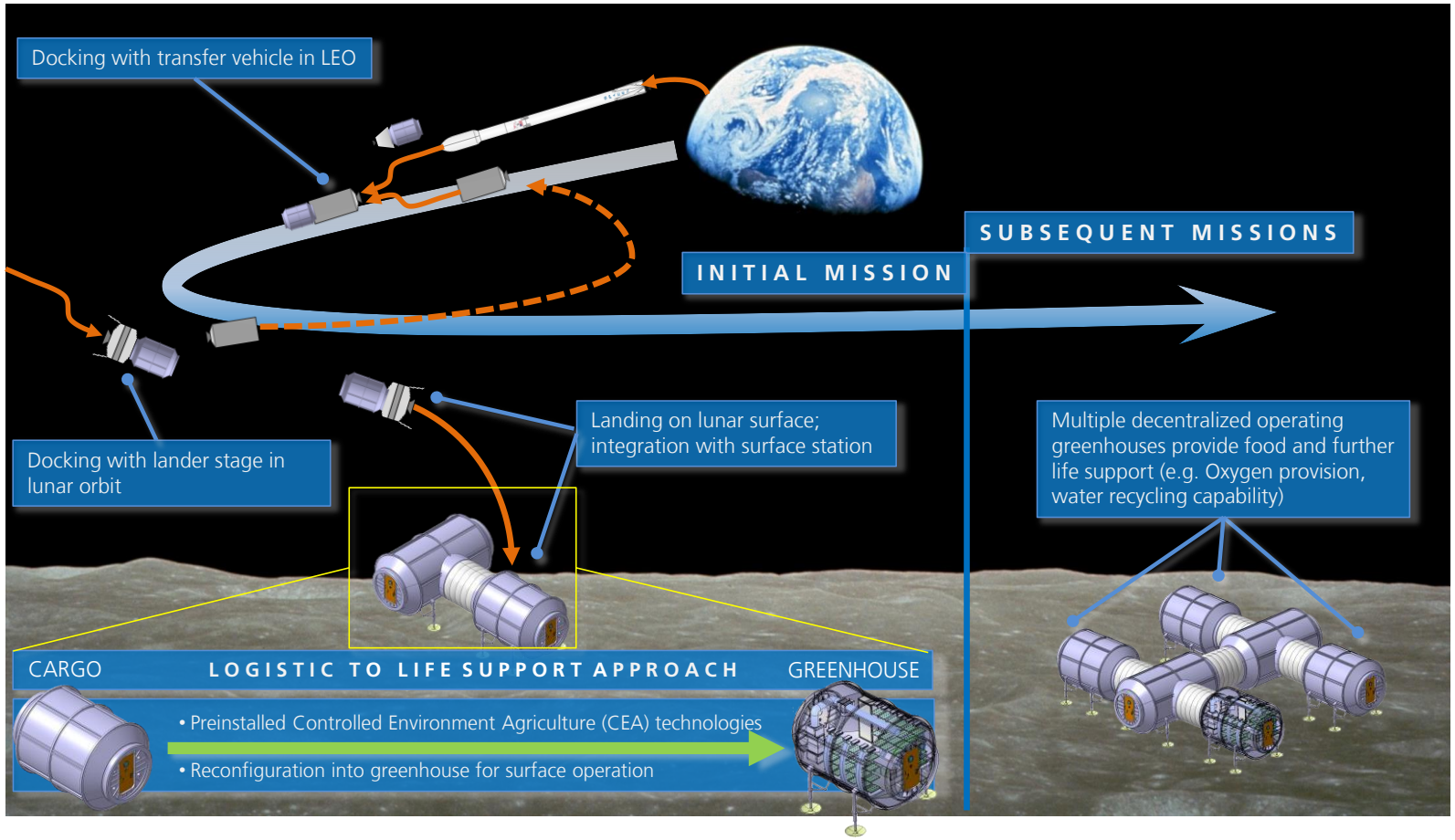
3.2 LAM-GROUND TEST DEMONSTRATOR

(Formal Project Name: EDEN NEXT GEN)

LUNAR AGRICULTURE MODULE (LAM)



LOGISTIC-TO-LIFE SUPPORT APPROACH



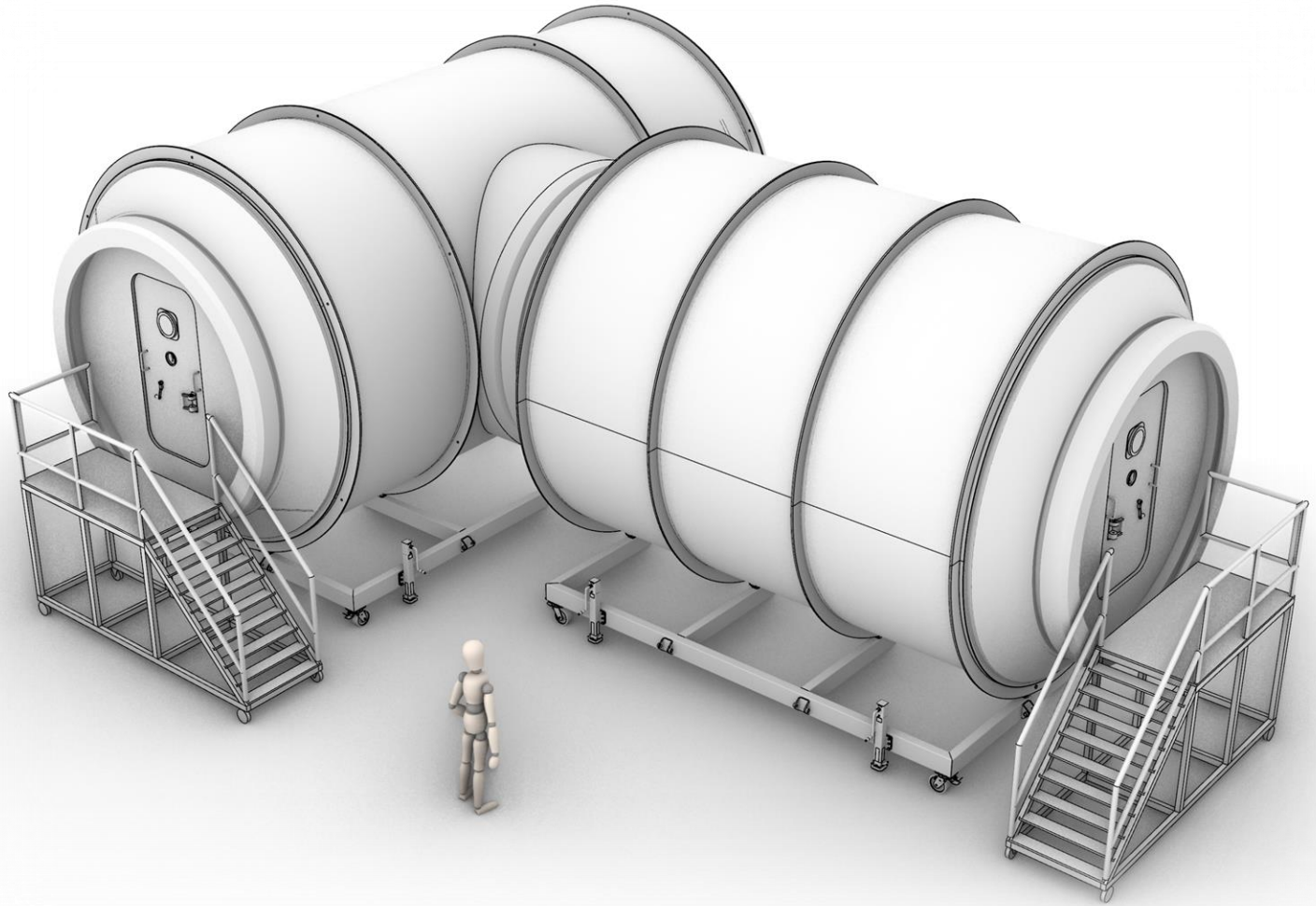
Initial Mission: Cargo delivery to Moon

Second Mission: Life Support Module

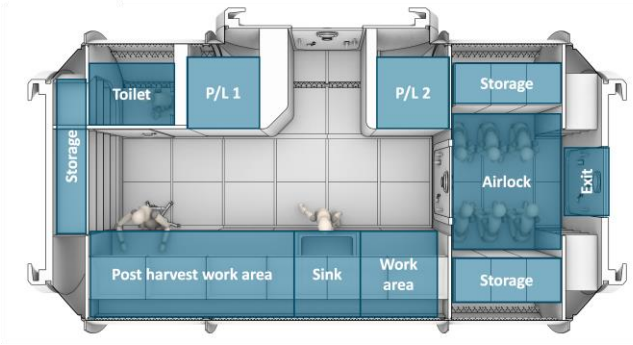
- Space-ready design
- Real testbed towards first Lunar Agriculture Module
- Transition to industry for later space hardware

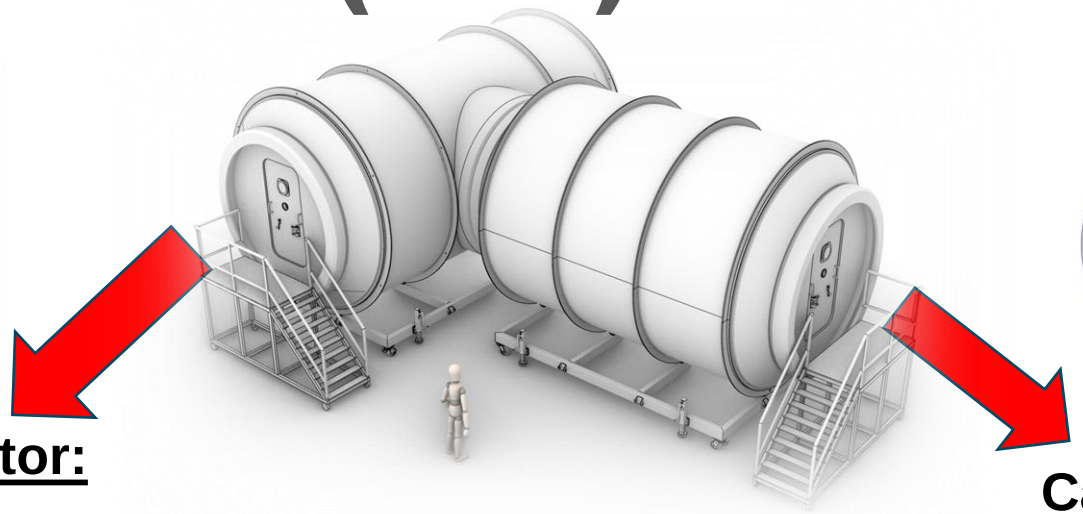
Food Provision | Air Revitalization | Water Recycling | Well-being

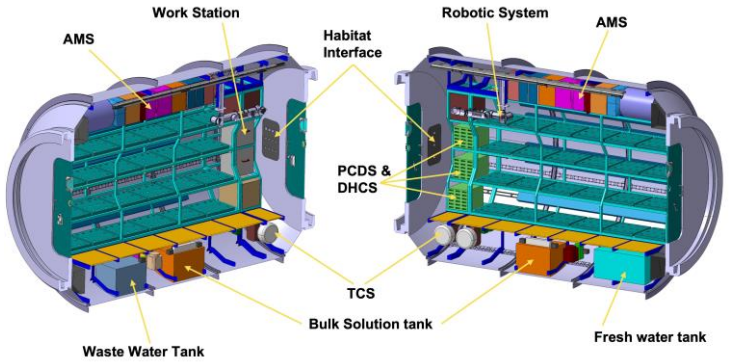
LAM GROUND TEST DEMONSTRATOR (GTD)



LAM GROUND TEST DEMONSTRATOR (GTD)







Airlock/ Habitat Simulator:

- Integrated laboratory (Sample & consumables storage)
- Food Processing Facility => (“Space Kitchen”)
- Food storage technologies
- Waste management interfaces

Cargo/Greenhouse Module:

- Production of edible crops
- *Pick & Eat* cultivars, but also other crop types

Seed-to-Meal Approach

Extended food storability

Space Kitchen

Other food technologies

Main greenhouse system

INTERNATIONAL PARTNERSHIPS

Canadian Space Agency

- Official LoI signature of CSA at IAC in Paris 2022
- Long-term partnership within DLR's roadmap
- Subsystem contribution by CSA for Ground Test Demonstrator (GTD)
  - First CAN industry call is coming out in May 2023
  - S/S: NDS, ILS, PHM
  - Joint DLR/CSA call for industry proposal for GDT
- No exchange of funds (Barter only)
- Dedicated exchange (Conrad Zeidler Abordnung)

Official signature of between CSA and DLR during IAC 2022 (left to right: Lisa Campbell (CSA), Anke Kaysser-Pyzalla (DLR), and Anke Pagels-Kerp (DLR).

FURTHER INTERNATIONAL COLLABORATIONS

NASA

- Joint mission to Antarctica (EDEN ISS)
- Exploration Systems Development Mission Directorate

ASI

- Strong involvement within the CEA domain
- Interested, but need more information

Industry

- Multiple interests and ambitions by various industry partners
- Integration of already developed physical/ chemical life support systems or other related systems

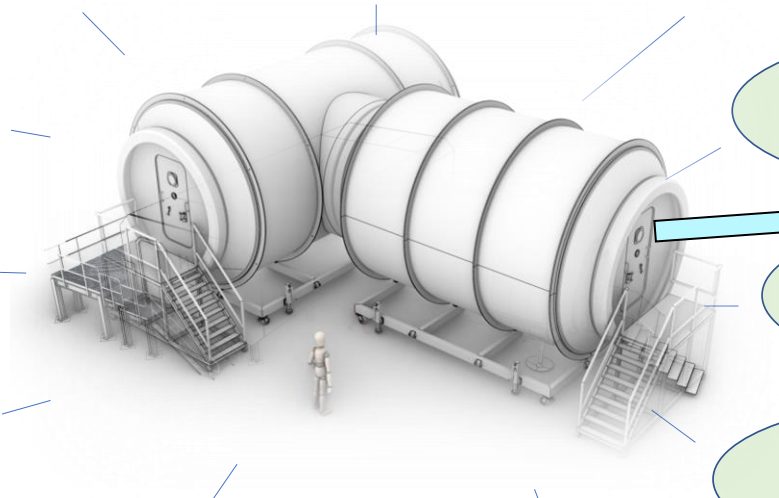
UNIQUE R&D PLATFORM

Crew Time Optimization

Input & Output Investigations (e.g. H_2O, Gases)

CEA Technology Testing & Validation

AI-based Plant Health Monitoring



Space-ready Design Testing, Humans-in-the-loop

Optimization of Biomass Output (qualitative & quantitative)

Microbiological Investigations

Matured Processes for Operations & Maintenance

Crop & Cultivar Selection

Robotic Enhanced Support Systems & Automation

Holistic Grow Recipes

International Mission Control Centers

DLR Mission Control Center (MCC)

Scientist Community

- Multifaceted research scope
- Open for international collaborations
- Invitation to industry, universities, and research center

2.3 EDEN 2.0 AT NEUMAYER STATION-III

EDEN 2.0 in NM III

EDEN 2.0: Different Production Mode

Summer season mode:

- Increased biomass output
- Additional grow levels
- Less crop variety

Winter season mode:

- Less biomass output
- More variety of crops
- More psychological aspects

Summer crew

Winter crew

EDEN 2.0 in NM III

TALL-GROWING CROPS CULTIVATION AREA

SUMMER MODE

WINTER MODE(with comfort lighting)

ENTRANCE VIEW

Plant cultivation lighting

Comfort lighting

3.5 TECHNOLOGY TRANSFER

HUMANITARIAN SYSTEMS: MEPA

Initial Situation

- Based on space greenhouse technology for Moon & Mars (EDEN-ISS)
- Earth: **Humanitarian crisis scenarios** with breakdown of local agriculture
- Earth quakes, droughts, floods, hurricanes, …
- Political unrests

Deployment scenarios

Earthquakes

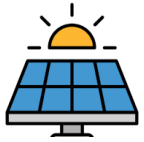
Refugee camps

Droughts

Floods

Key Features

Compact transport



Independent from power grid - solar powered

Plug & Grow: Fast and easy Assembly

Dynamic control/ Implementation of weather data/ cross-linked systems

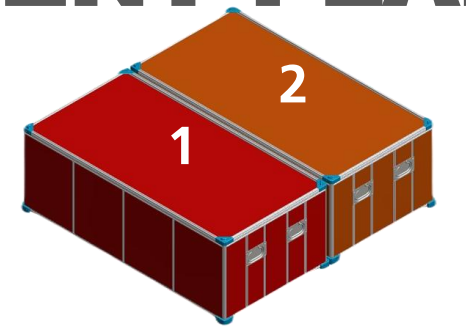
Soilless cultivation (Closed-loop/ resource-efficient)

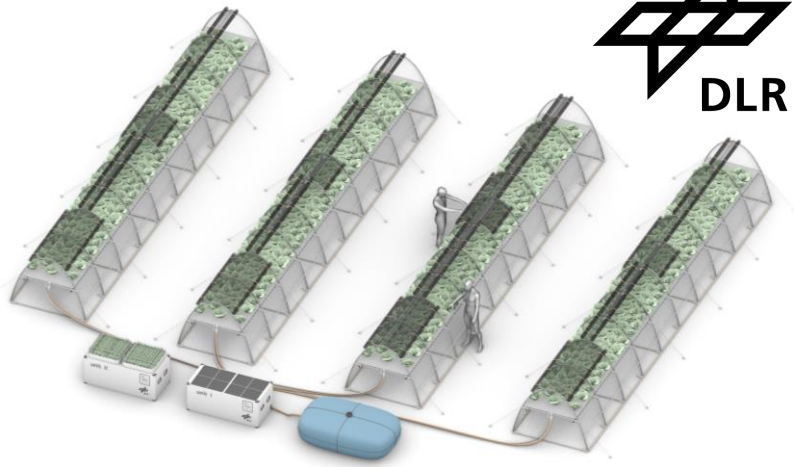
In-situ food provision in extreme situations

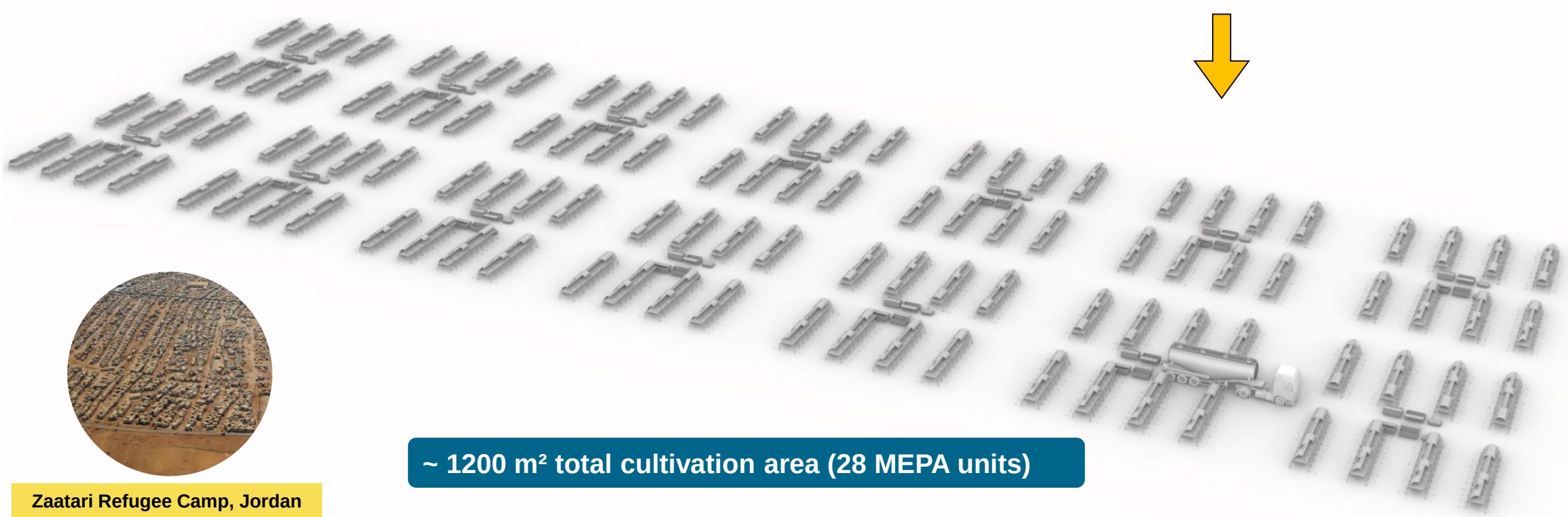
MEPA
HUMANITARIAN HYDROPONICS

MEPA DEPLOYMENT PLAN

28 units per 40 ft Container





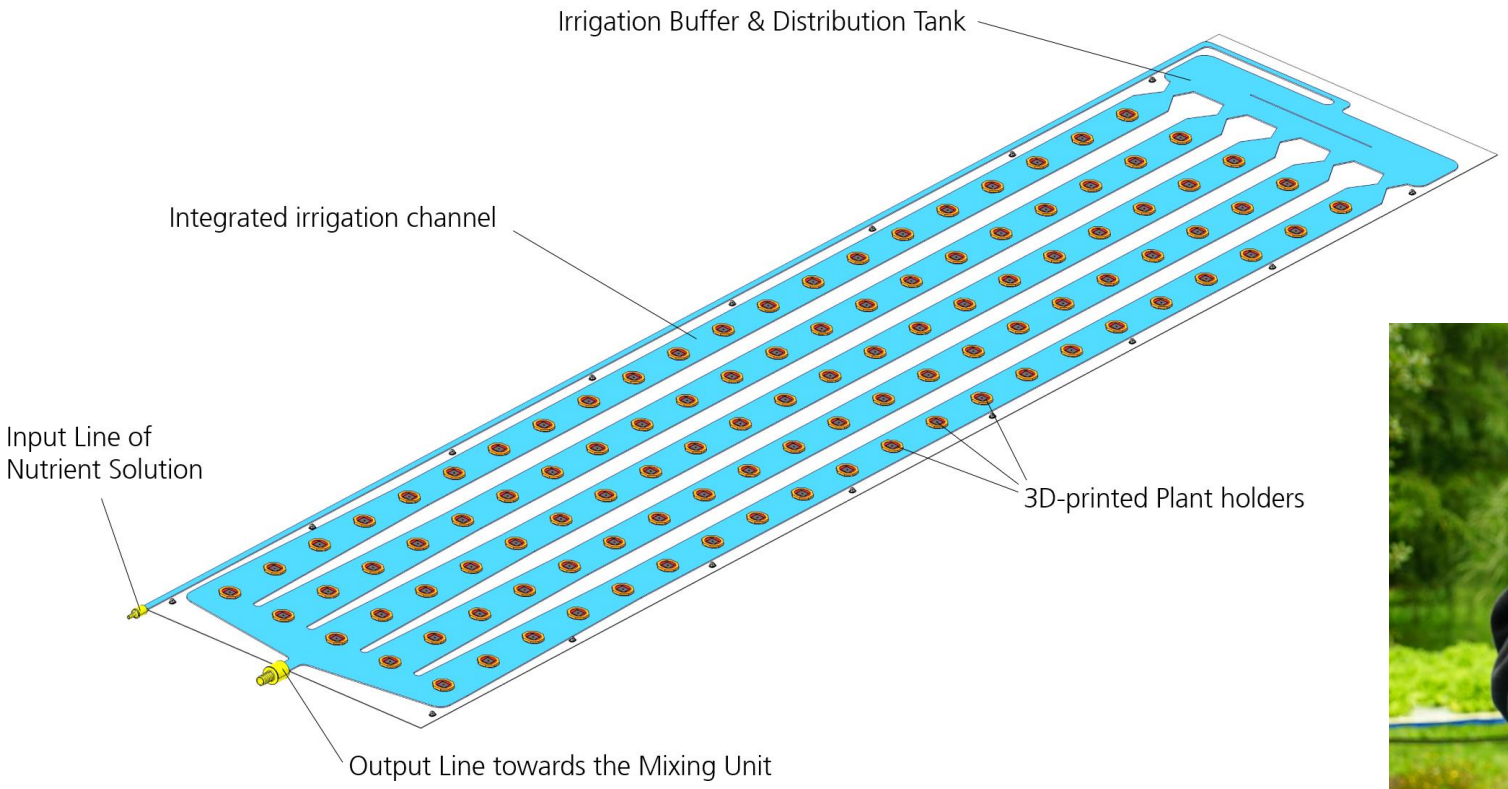


Zaatari Refugee Camp, Jordan

~ 1200 m² total cultivation area (28 MEPA units)

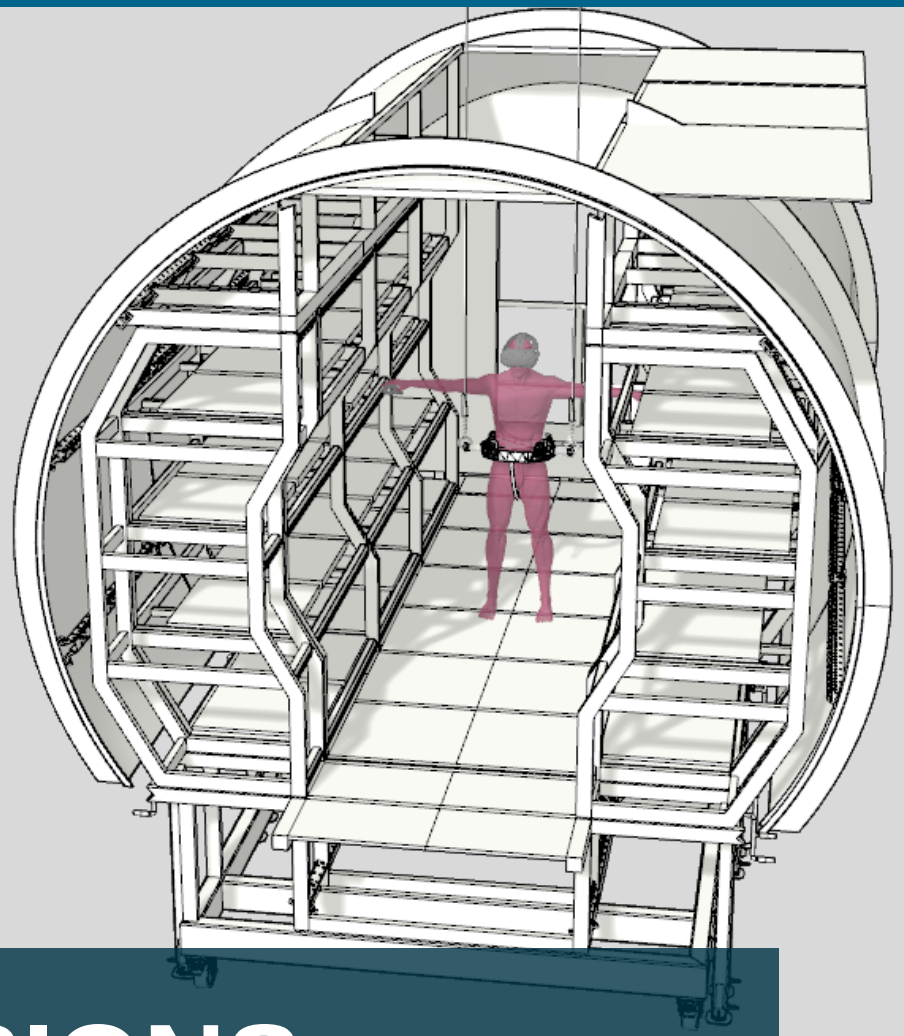
MEPA SYSTEMS

Seed Cultivation Mat (SCM):

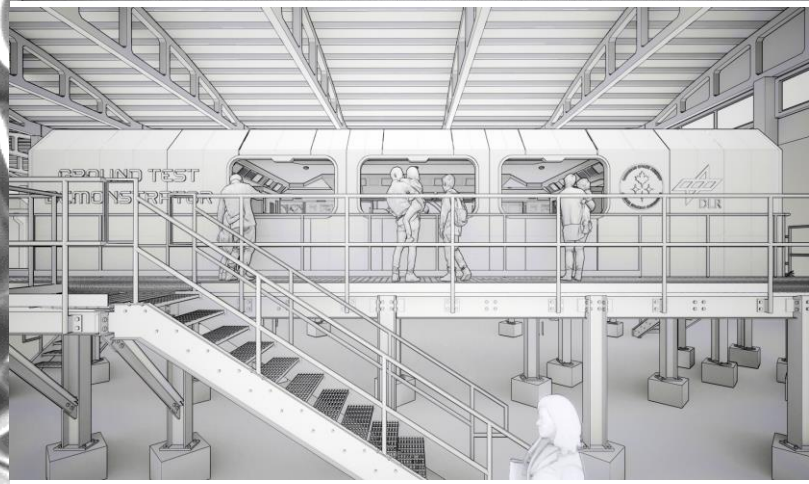


1) POST-CULTIVATION & SPACE FOOD

1) HUMAN FACTORS FOR LAM



3.4 RESEARCH EXPANSIONS



1) POST-CULTIVATION & SPACE FOOD

SPACE FOOD SYSTEM

“We need to start thinking of the food system as a whole“

Processing

Food Storage

Food Production

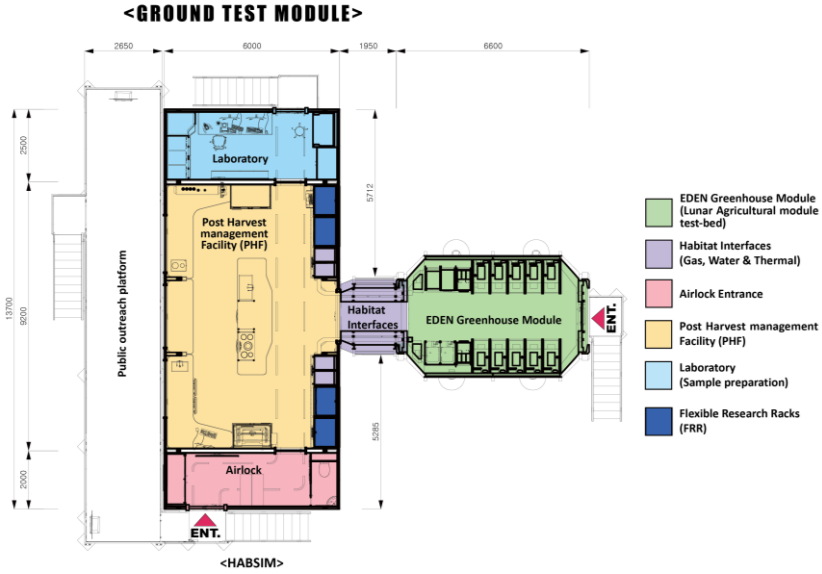
Crew-Health & Performance

Inedible Biomass Utilization

Technological Synergies

Space Compatible Appliances

Innovation accelerator

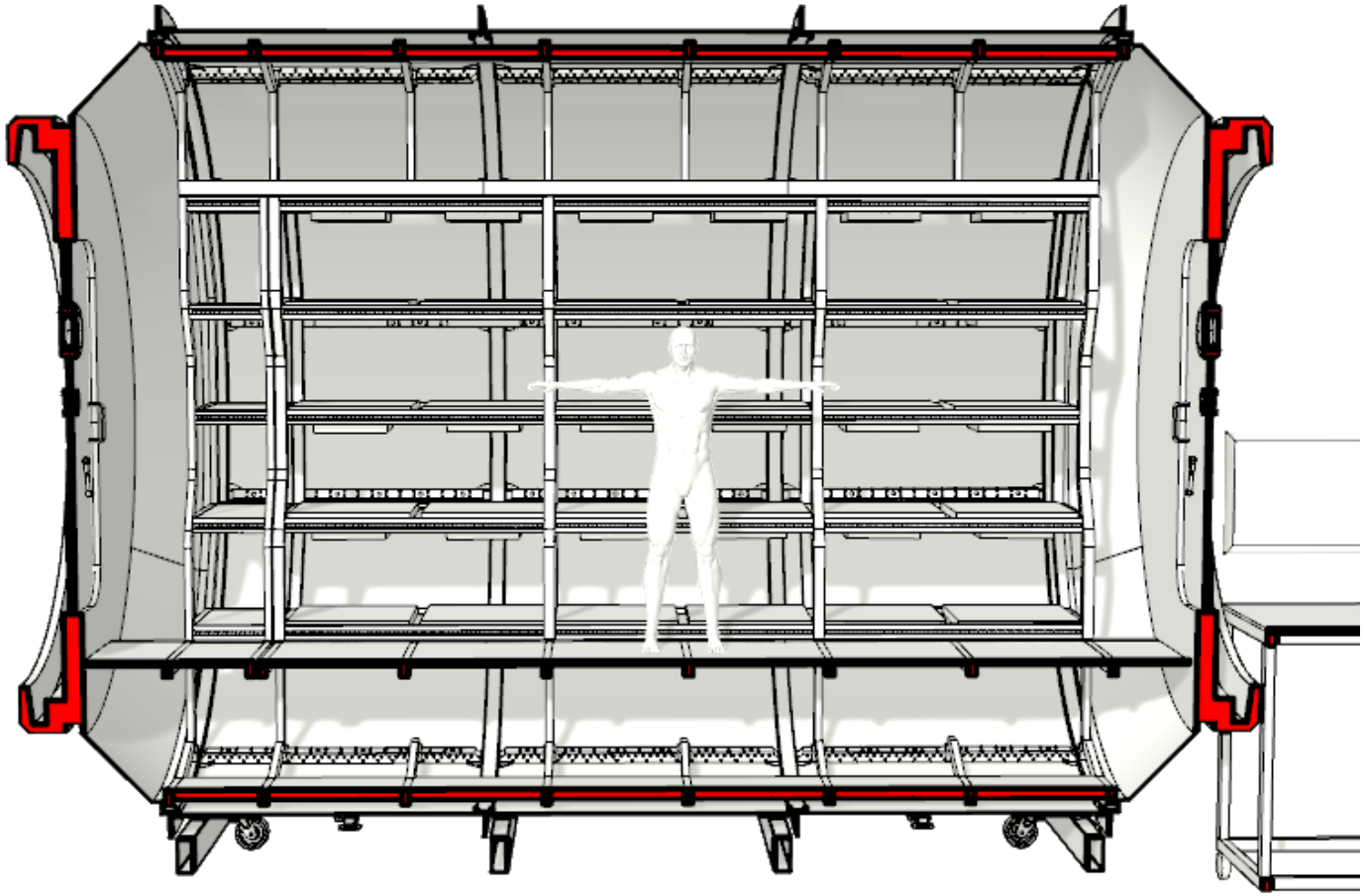


Nutrition

Food Saftey

Food Quality

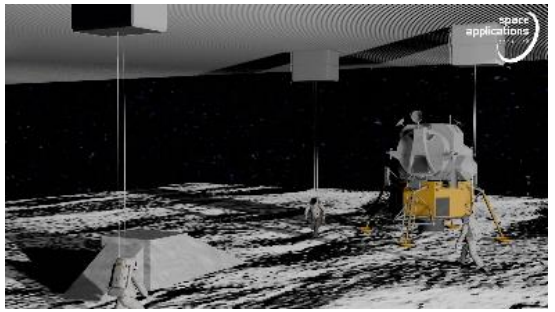
Technology transfer

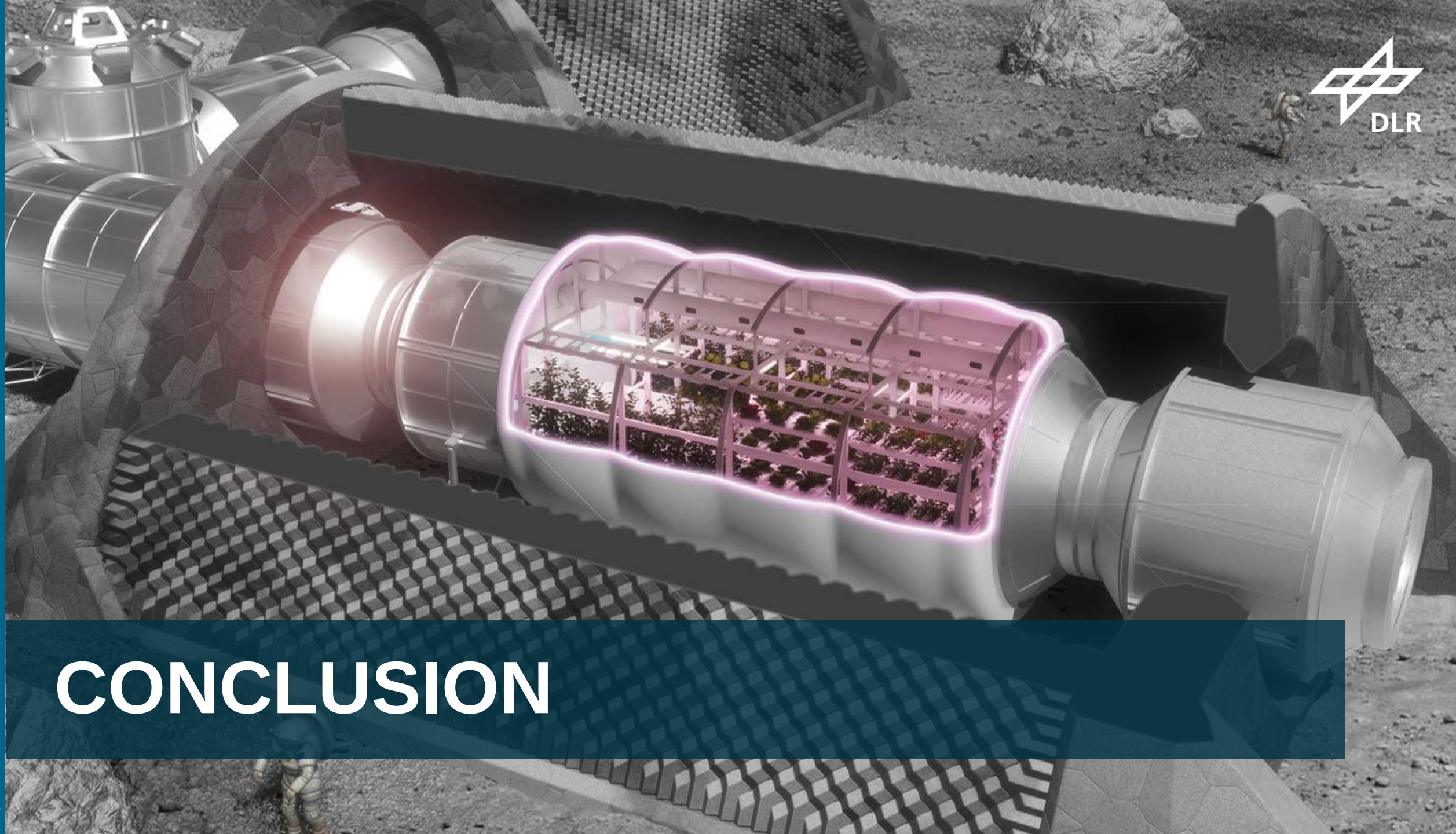


2) HUMAN FACTORS FOR LAM

SIMULATING REDUCED GRAVITY ENVIRONMENT

Mobile Gravity-Offloading System (MOGOS) in Luna Facility in Cologne





CONCLUSION

RESEARCH & INDUSTRY NETWORK

DLR

Industry

ThalesAlenia Space
LIQUIFER SPACE SYSTEMS
AIRBUS DEFENCE & SPACE
STARLAB OASIS
Scanway imaging space
heliospectra
SPARTAN SPACE
ENGINSOFT
RIJK ZWAAN
CREATING A CLIMATE FOR GROWTH PRIVA
agrilution
OSRAM
TELESPAZIO a LEONARDO and THALES company
ISAAC
Bock bio science
OHB

Space Agencies

NASA
CSA ASC
esa

Research Institutes

AWI
Canada NRC·CNRC
UFZ HELMHOLTZ Zentrum für Umweltforschung
National Research Council of Italy

Universities

UNIVERSITY of GUELPH
TECHNISCHE UNIVERSITÄT DRESDEN
Universität Bremen
UF UNIVERSITY of FLORIDA
THE UNIVERSITY OF ARIZONA
Wrocław University of Science and Technology
Università degli Studi di Napoli FEDERICO II
WAGENINGEN UNIVERSITY & RESEARCH
Technische Universität Braunschweig
HUMBOLDT-UNIVERSITÄT ZU BERLIN
SLU

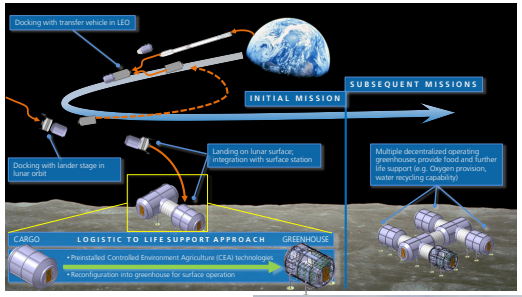
Humanitarian Organizations

WFP United Nations World Food Programme
Technisches Hilfswerk
PLAN INTERNATIONAL
ADRA

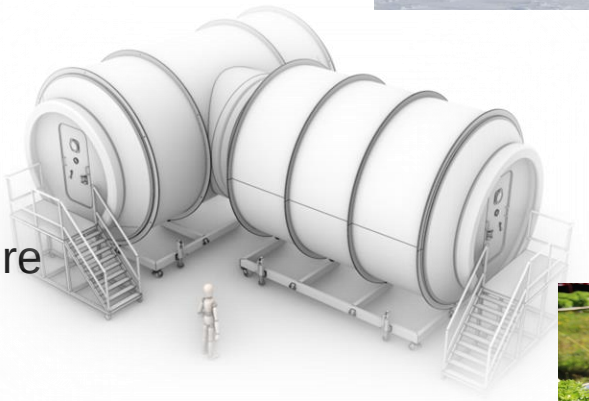
In Total: 38 partners on national & International level

SUMMARY & CONCLUSION

- DLR roadmap for BLSS => Long-term R&D program (2020-2030)
- EDEN ISS => Testing CEA technology in space analogue environment, Antarctica
- EDEN LUNA => Astronauts-in-the-loop @ LUNA Facility
- LAM-GTD: First and fully integrated test greenhouse module for the Lunar surface (logistic-to-life support approach) => CSA as full partner.
- EDEN 2.0 @ Antarctica => Psychological tests
- Tech. Transfer => MEPA: Humanitarian Hydroponics
- Space Food System & Human Factor for space agriculture



EDEN luna



Thank you for your Attention!

THANK YOU

Deutsches Zentrum
für Luft- und Raumfahrt

Institut für Raumfahrtsysteme

Excellence in Space Systems Research

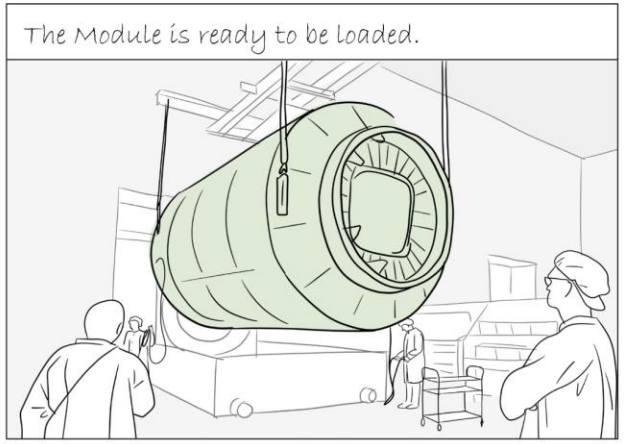
We enable ambitious space missions of tomorrow.

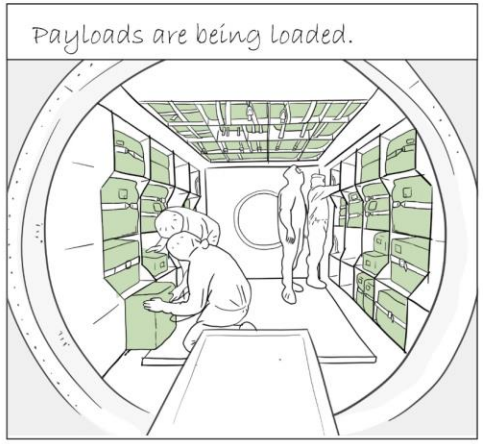
DLR

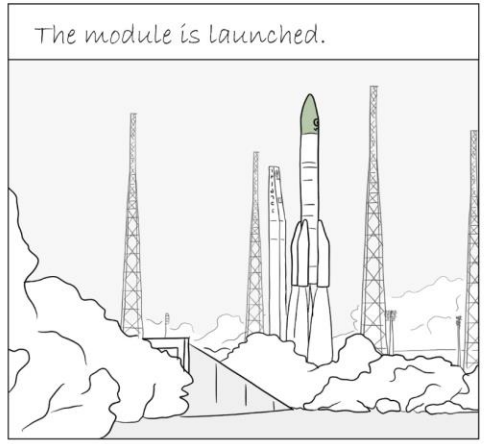
CANADIAN SPACE AGENCY
AGENCE SPATIALE CANADIENNE

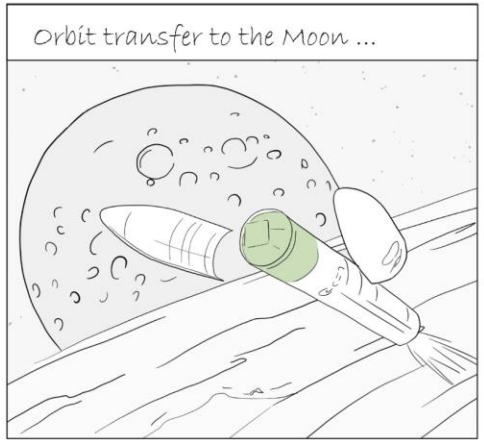
L2L

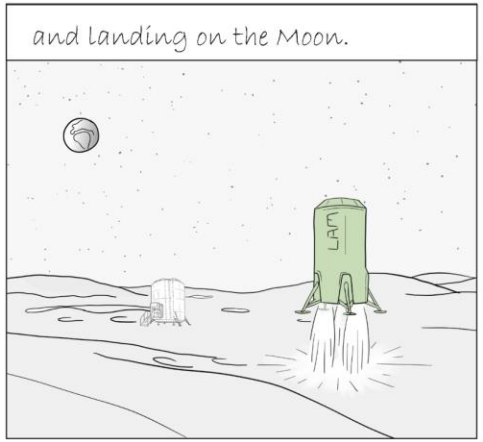
Logistic to Life Support System

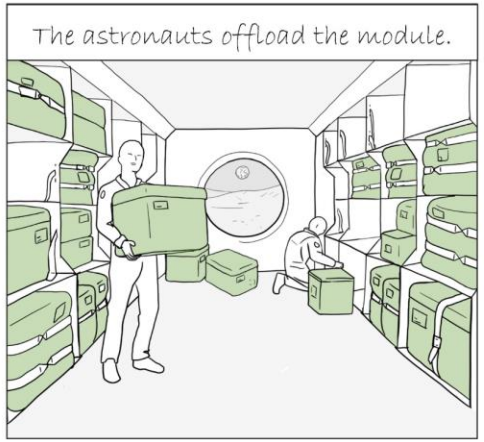


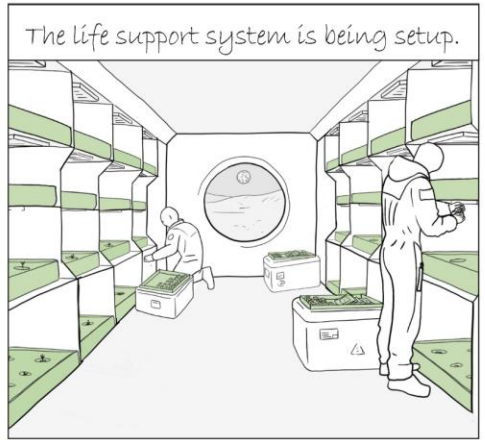


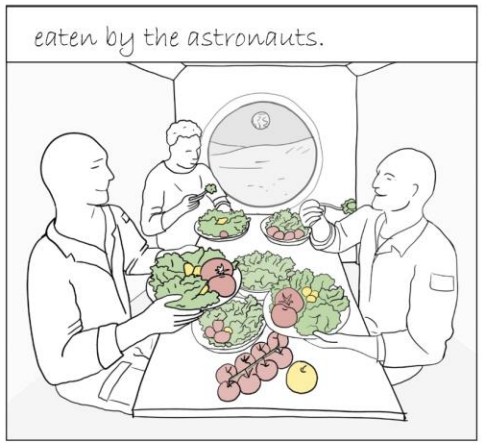


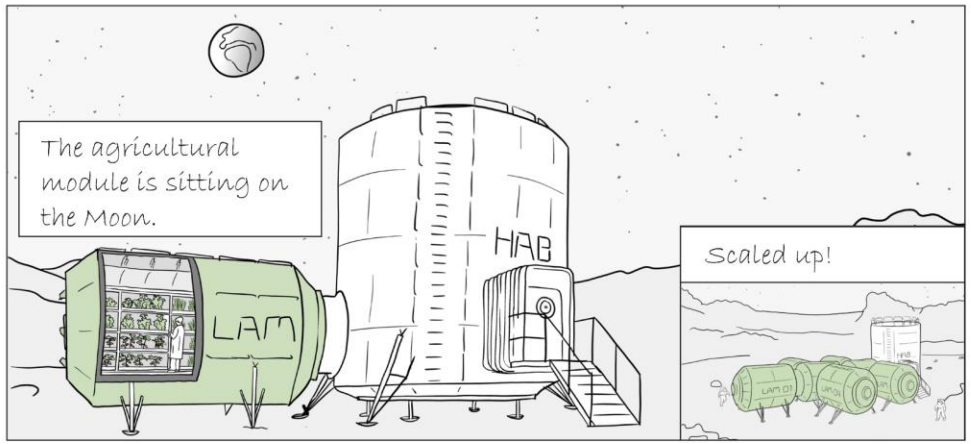












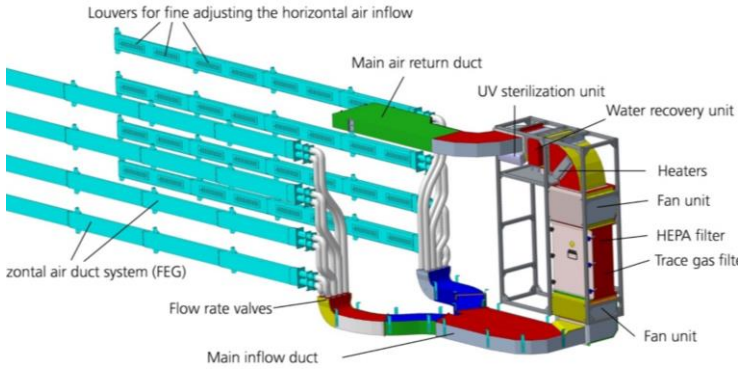
THE EDEN ISS: KEY TECHNOLOGIES

Controlled Environment Agriculture (CEA) Technologies

Nutrient Delivery System

Illumination Control System

Atmosphere Management System

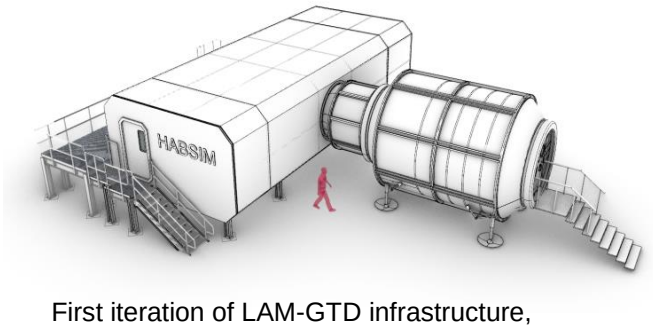


- Independent biomass production & Closed-Loop Environment
- Up to 50 % faster production
- Up to 60 % higher yields
- Exact control of taste, morphology, and useful phytochemicals

Planetary Infrastructures

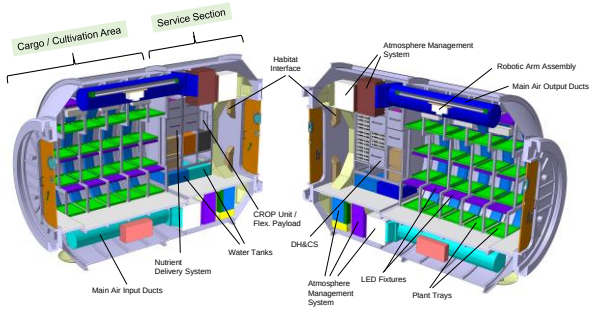
Bio-regenerative Life Support Systems

- Focus: Lunar Agricultural Module – Ground Test Demonstrator (LAM-GTD)
- Logistic-to Life Support Approach => Reoutfit of empty cargo modules into plant cultivation modules
- Collaboration project with CSA; Planned collaboration with NASA and ASI
- LAM-GTD: All subsystems fully integrated; Realistic mass flows; Low pressure environment analogue to Lunar habitat (down to 57 kPa)
- AIT Phase starts in 2027; Testing campaign starts end of 2028



First iteration of LAM-GTD infrastructure, including a mock-up habitat (HABSIM)

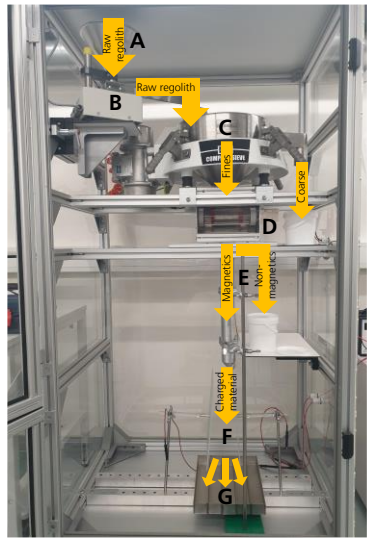
Focus on greenhouse developments for Moon/ Mars



Logistic-to-Life Support Approach for a greenhouse

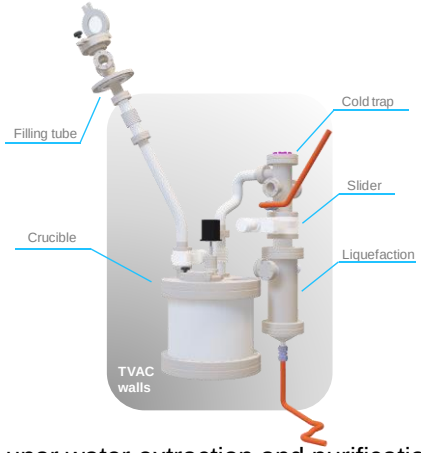
In-situ Resource Utilization (ISRU)

- Development of ISRU technologies for propellant and consumables production
- Combination of laboratory-scale experimental setups in relevant environment and simulations to raise the TRL to 5
- Water extraction and purification technologies, e.g. LUWEX project
- Regolith beneficiation process developments, e.g. for ilmenite enrichment for subsequent oxygen extraction



Regolith beneficiation laboratory setup

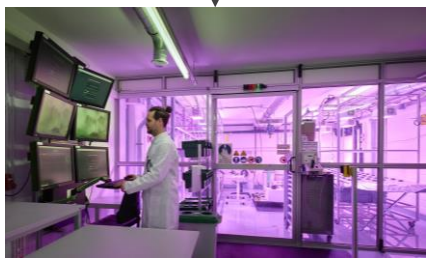
LUWEX
Validation of Lunar Water Extraction and Purification Technologies for In-Situ Propellant and Consumables Production



Lunar water extraction and purification technology demonstrator

FACILITY OVERVIEW

Institue of Space Systems



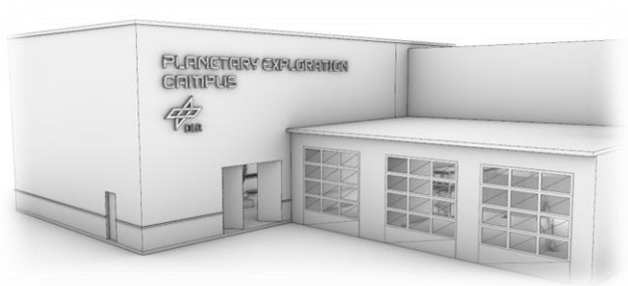
EDEN Lab.

Mission Control Center

3D Printing Lab.

EDEN ISS/ LUNA

ISRU Labor



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