EDEN ISS:
Analogue Testing of Plant Cultivation Technologies for Space

Dr. Daniel Schubert
Institute of Space Systems

22.06.2021

DLR

EDEN Initiative

- Founded in 2011 @ the DLR Institute of Space Systems (Bremen)
- System Analysis & Systems Engineering in the domain of Human Space Flight
- Investigation of Greenhouse Modules (GHM) and habitats (incl. crew)
- Daniel Schubert CV: Industrial Engineering at TU Berlin; PHD at University of Bremen

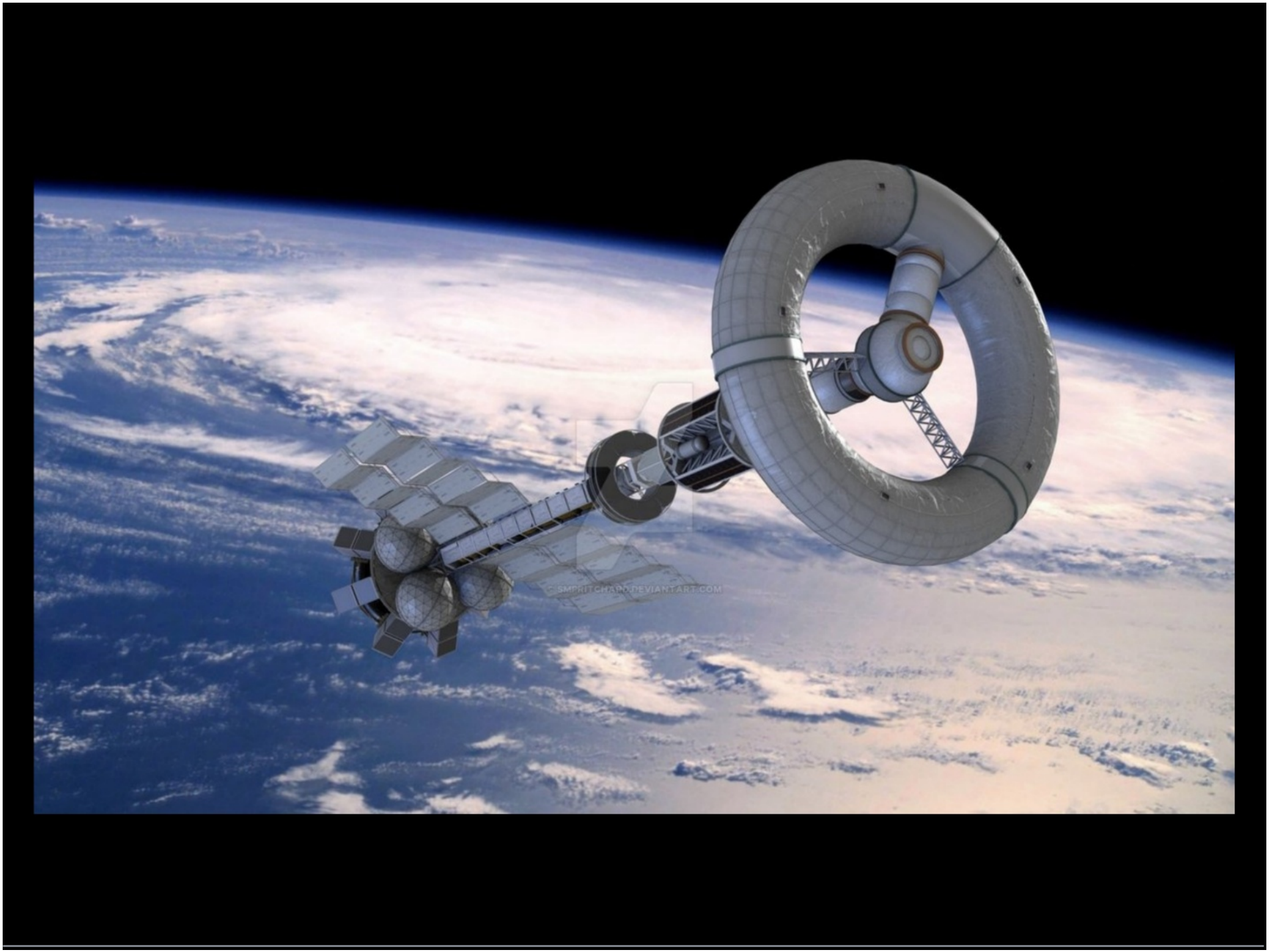
Dr. Daniel Schubert (Team Leader EDEN Initiative)

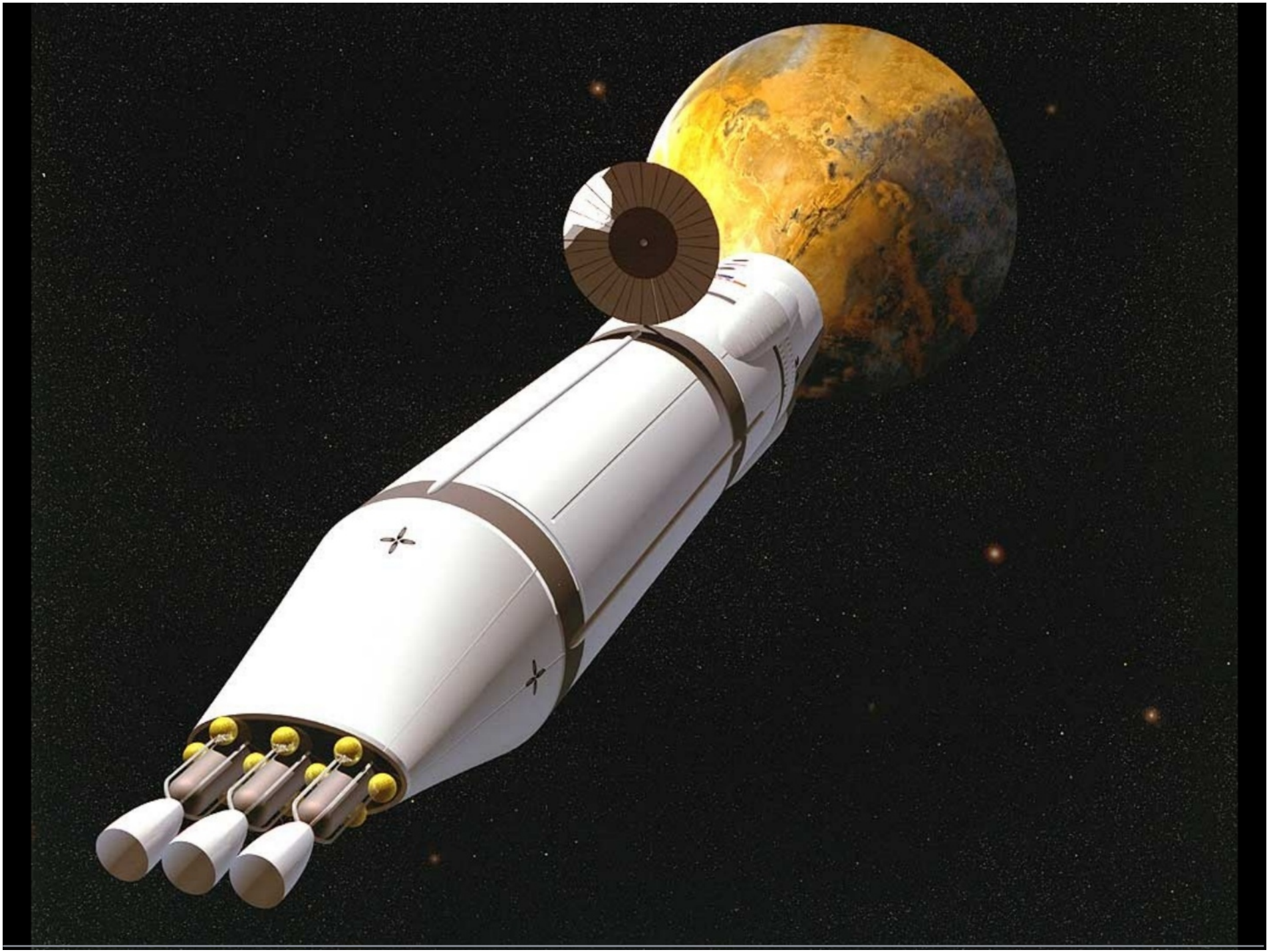
Yearly Reports:

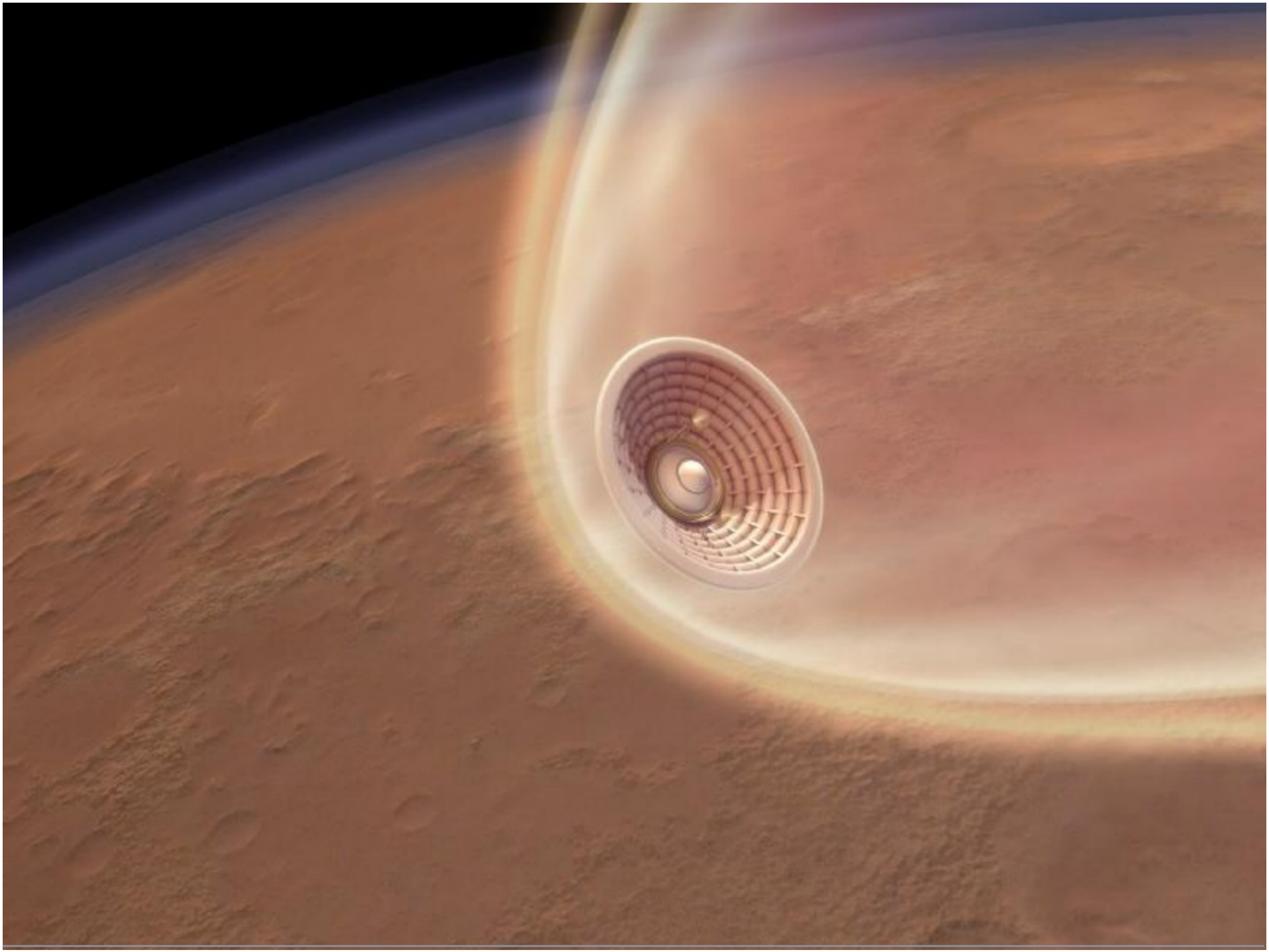
2014 2015 2016 2017 2018 2019

Online:
https://www.dlr.de/irs/DesktopDefault.aspx/tabid-11286/gallery-1/gallery_read-Image.46.27812/

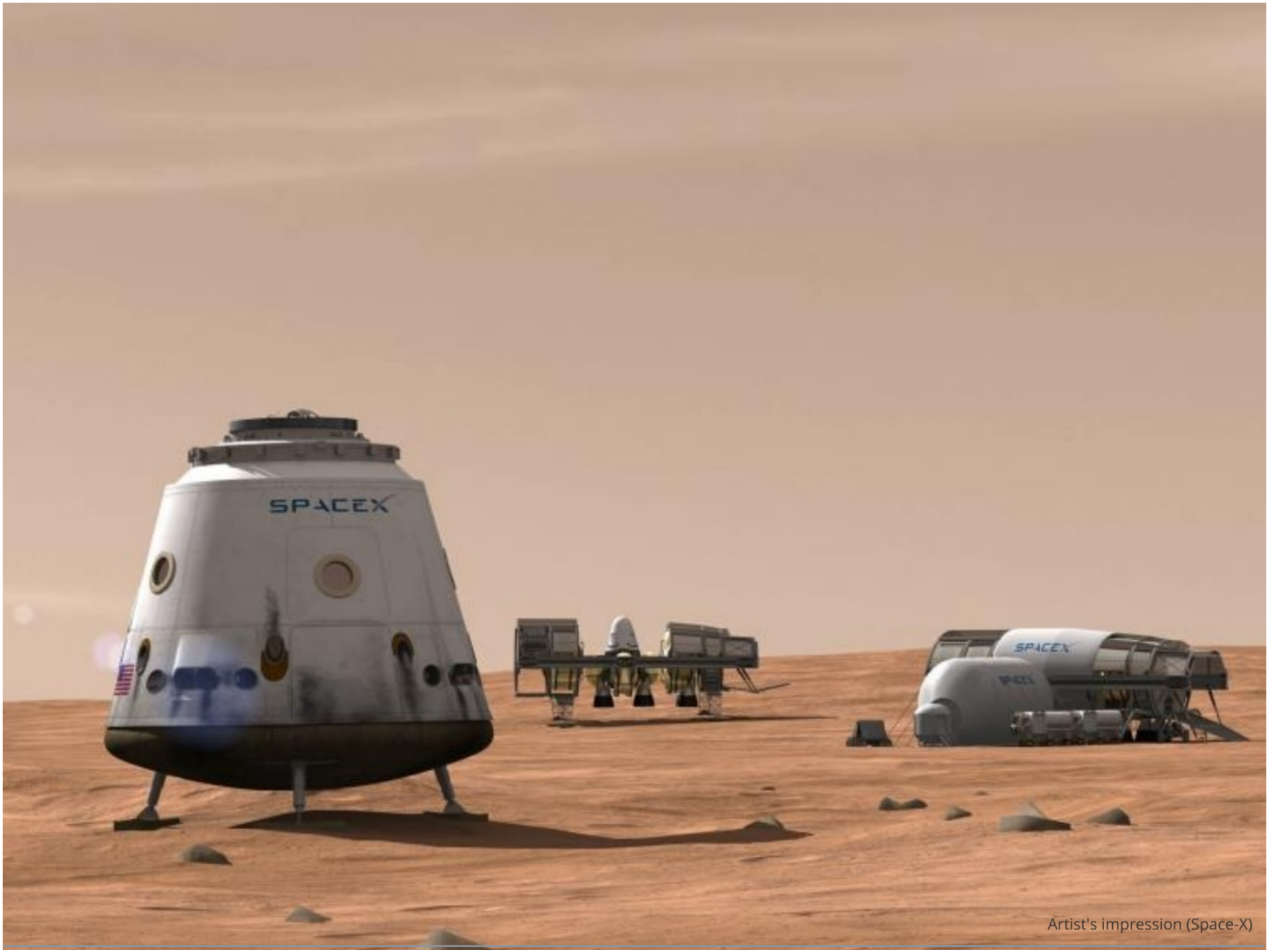
Human Exploration into the Solar System


SMPRITCHARD.DEVIANTART.COM



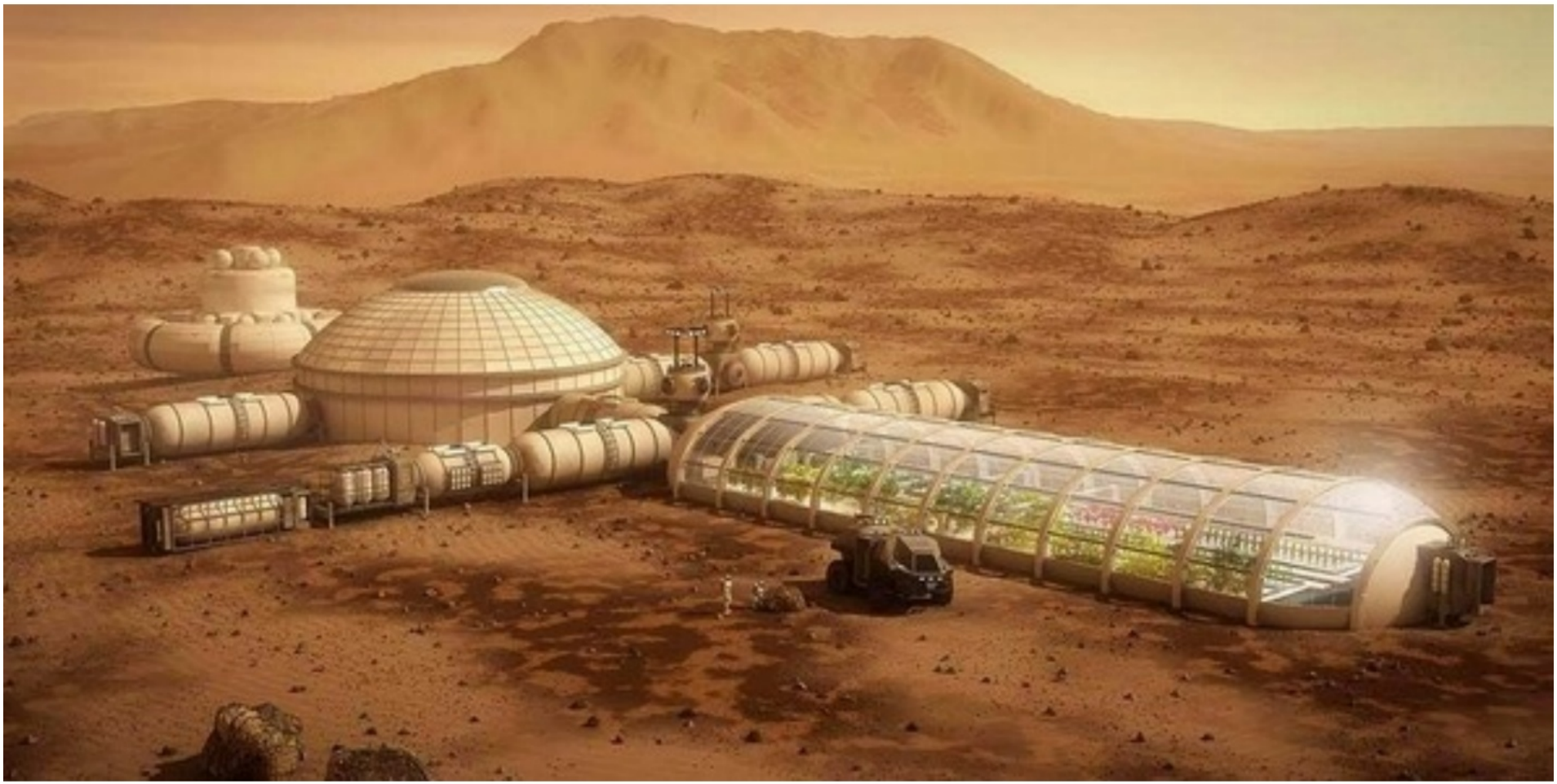


Artist's impression (Space-X)



Artist's impression (Space-X)

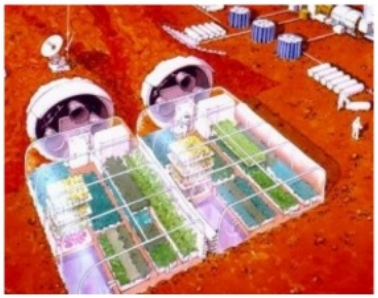
Artist's impression (Mars-one)



Bryan Versteeg/Spacehabs.com

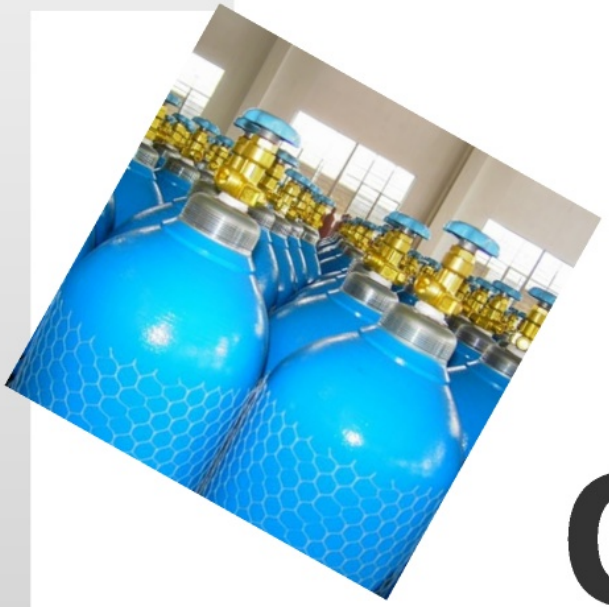
Greenhouse modules as an infrastructure element of habitats

Artist Impressions



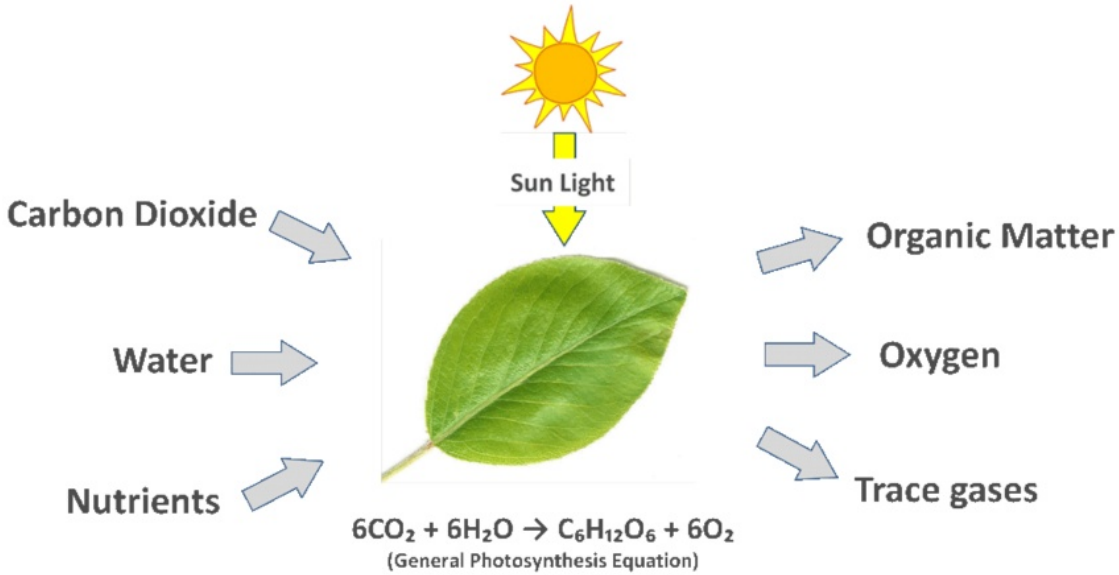
Why Plants?

Food

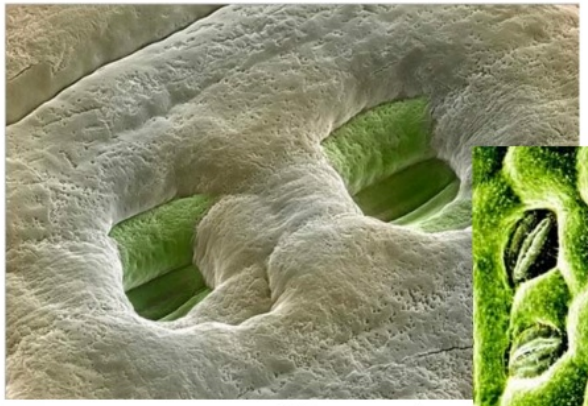



O2

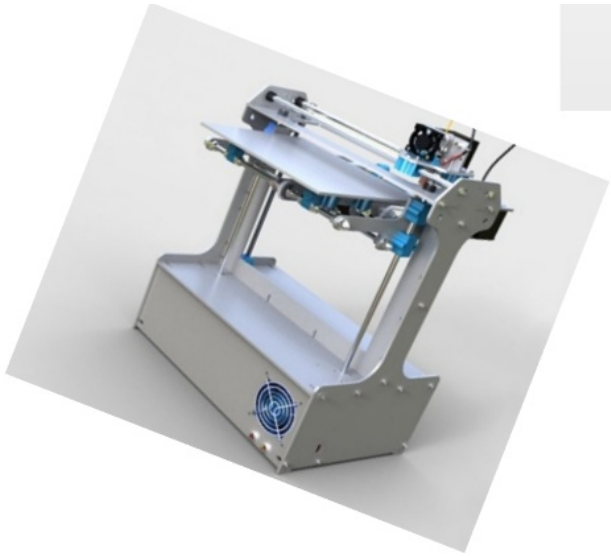
Oxygen


Sun Light
Carbon Dioxide
Water
Nutrients
Organic Matter
Oxygen
Trace gases
$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
(General Photosynthesis Equation)

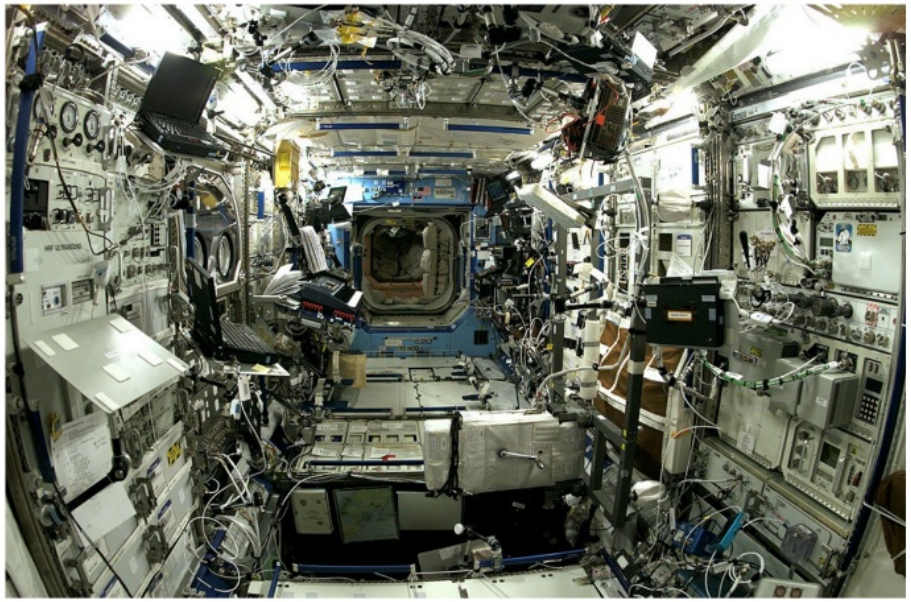
Water



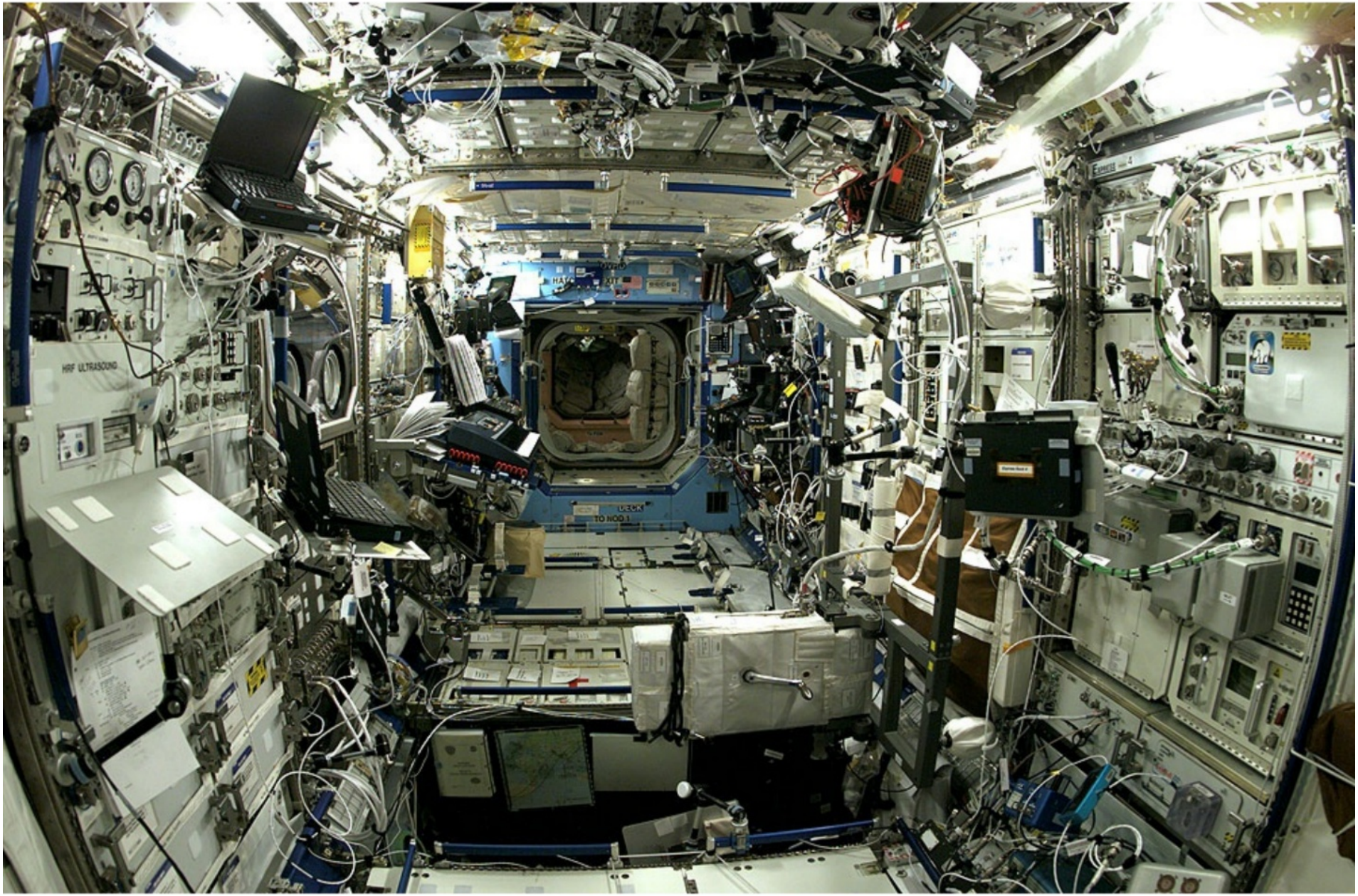
Stomata



Raw Materials



Well-being


HRF ULTRASOUND
DECK
TO NOD 1

Why do we take plants with us?

Antarctic Greenhouse System

Analogue Testing of Plant Cultivation Technologies

EDEN ISS

- H2020 Project, ~5M€
- 14 Partner from industry, universities, research institutes
- Space sector, Horticulture, Psychology, Polar research
- 8 Countries
- Start: 2015 End: 2019
- Analogue mission to Antarctica - German Neumayer Station III

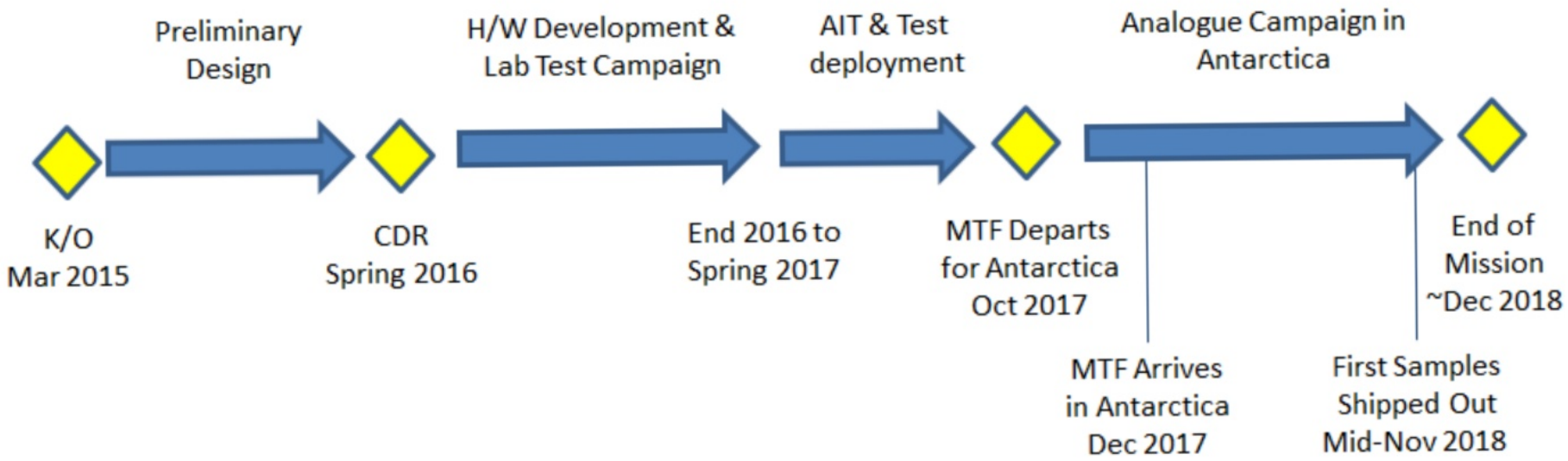

EDEN ISS
PLANT
CULTIVATION
TECHNOLOGIES

Why Analogue Testing in Antarctica

Analogue Testing at Neumayer Station III

- Crew size
- Isolation & resupply once a year
- Harsh environment
- Technology dependency
- Low biodiversity environment

Project Timeline:



Initial Target Plants:

Lettuce

Red Outrageous Lettuce

Rucola

Spinach

[...]

Tomato

Pepper

Cucumber

Radish

[...]

Strawberry

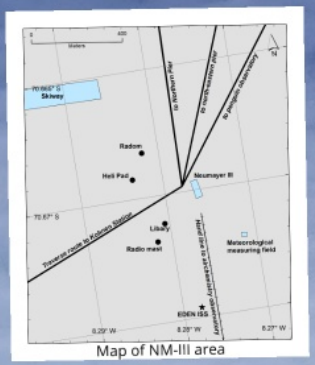
Different Herbs

[...]

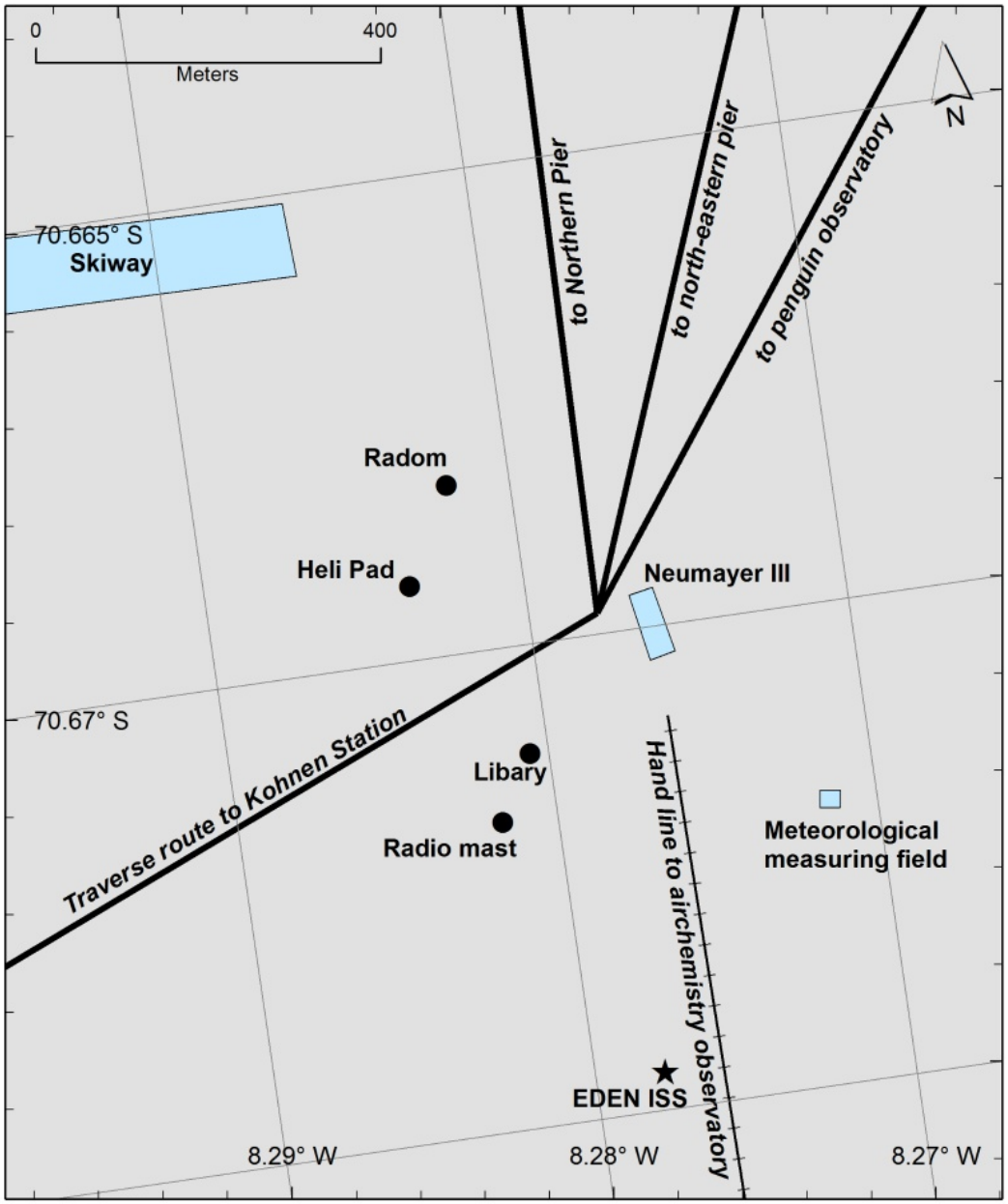
[fresh weight values]

EDEN ISS
Research Facility

EDEN ISS - Research Facility



Map of NM-III area



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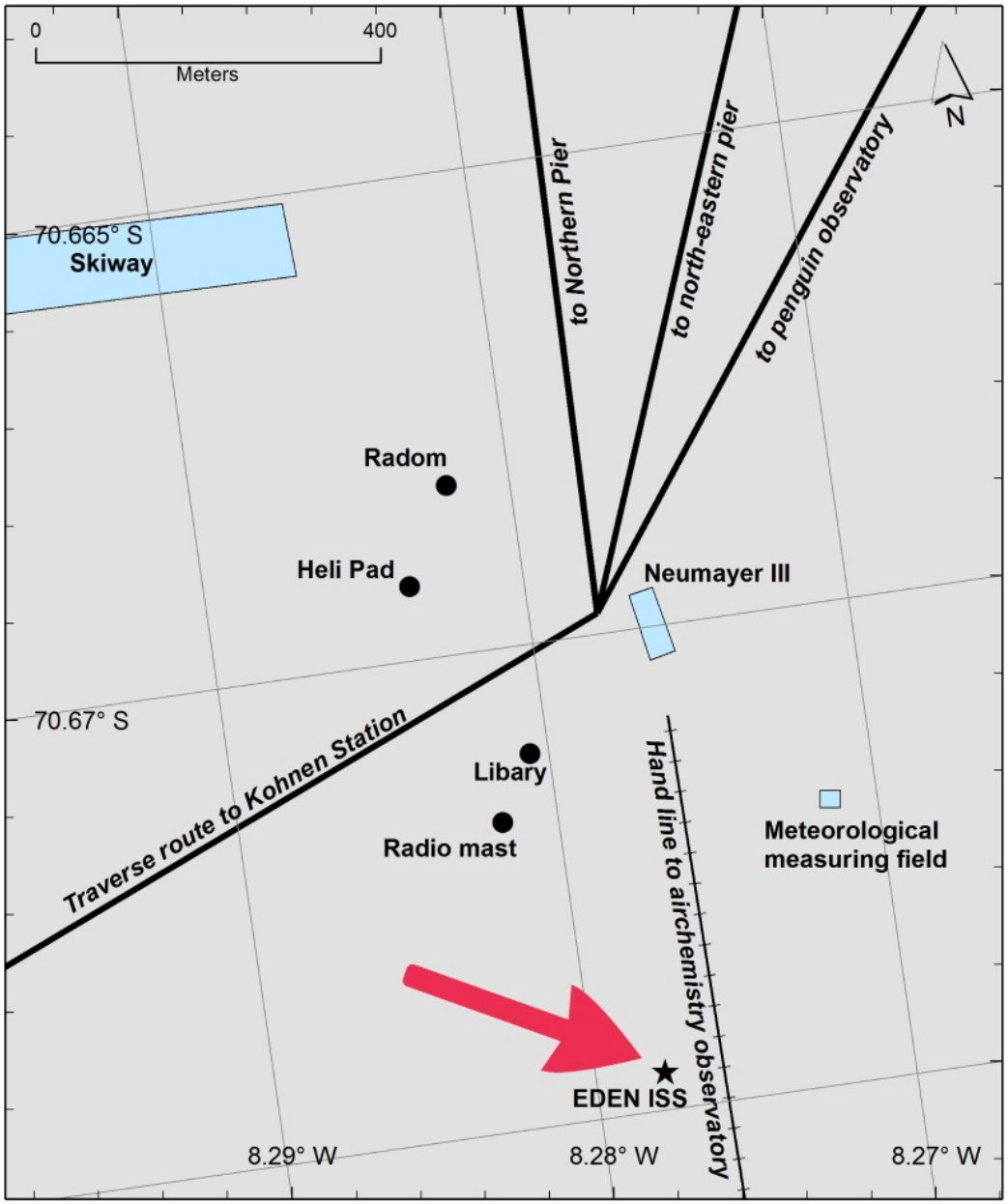

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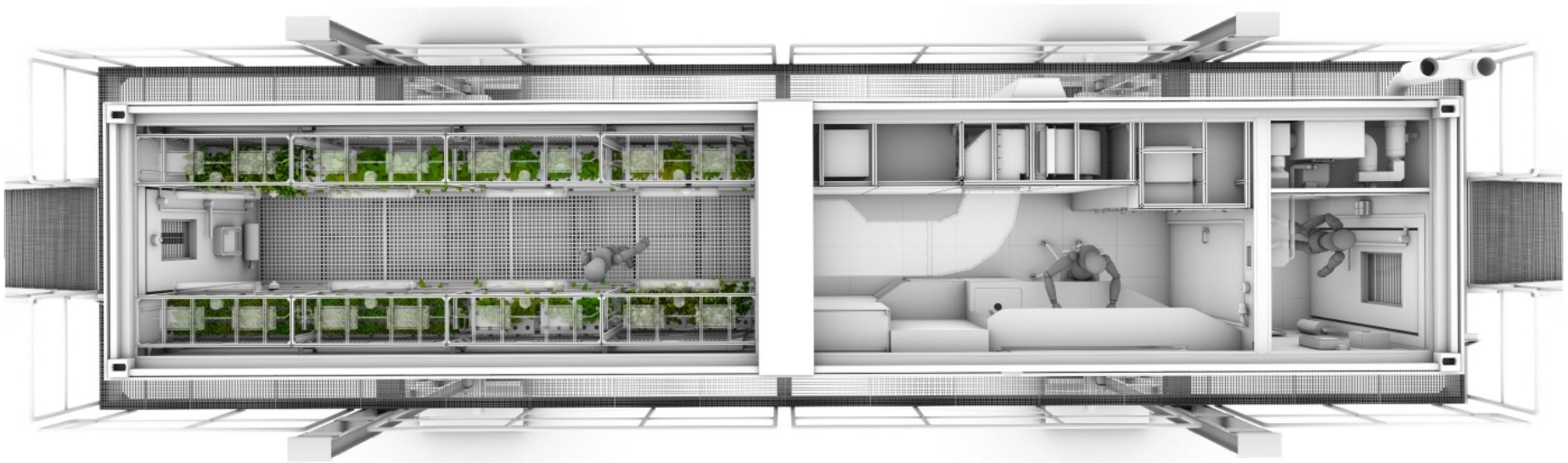
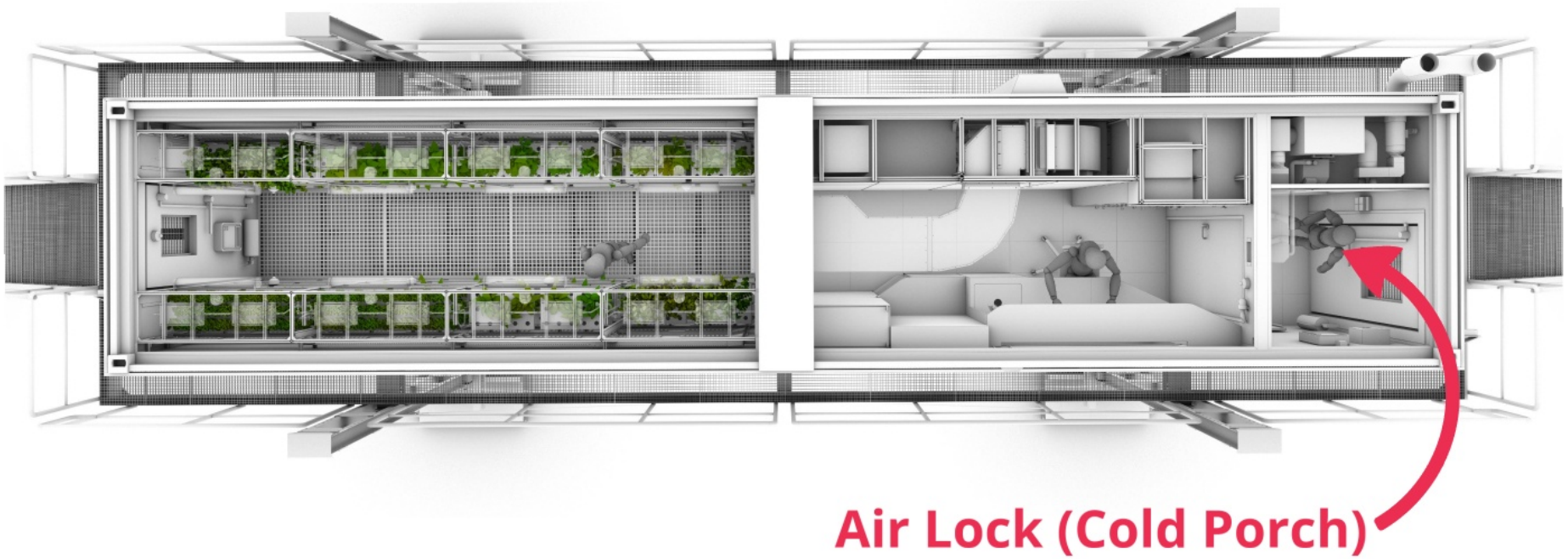
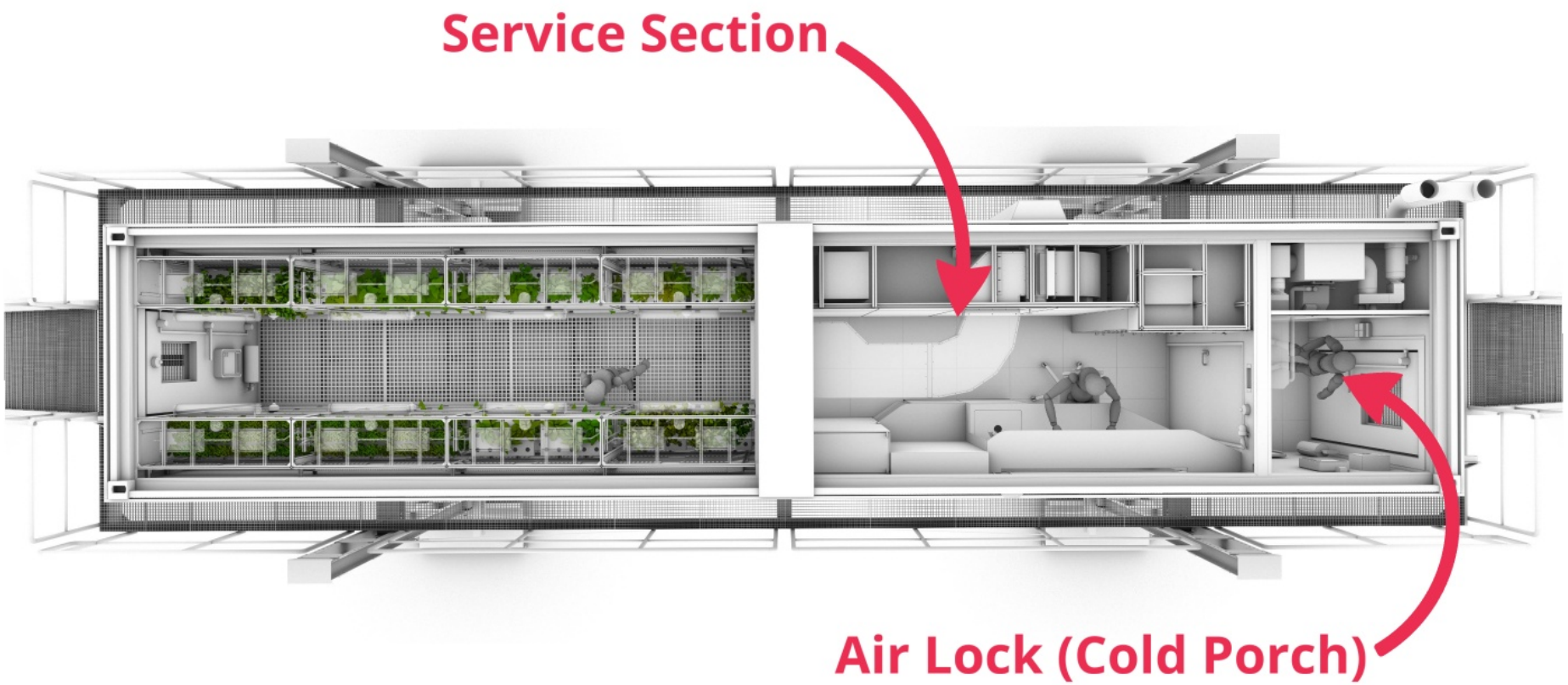
EDEN ISS - Research Facility



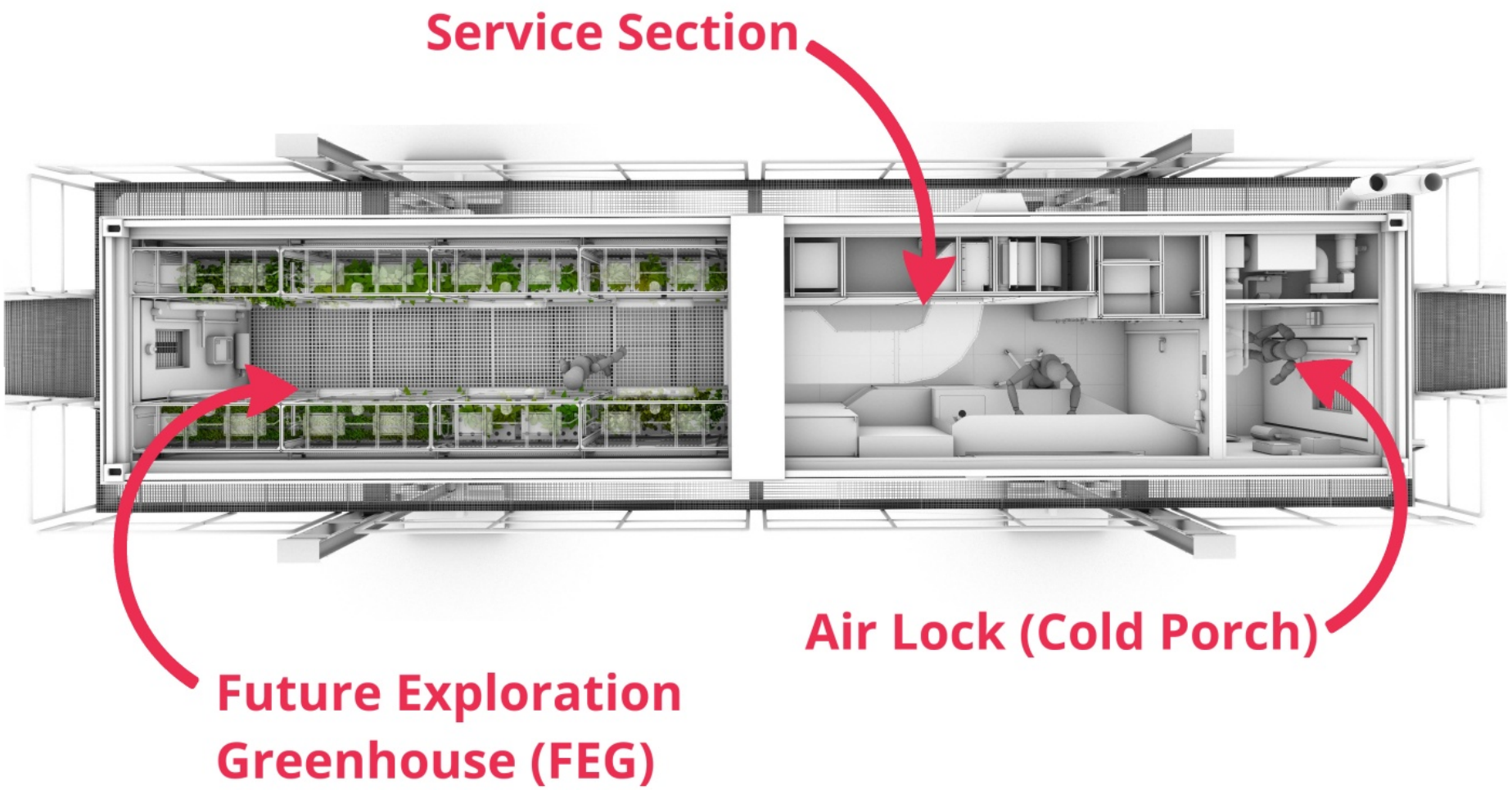
EDEN ISS - Research Facility



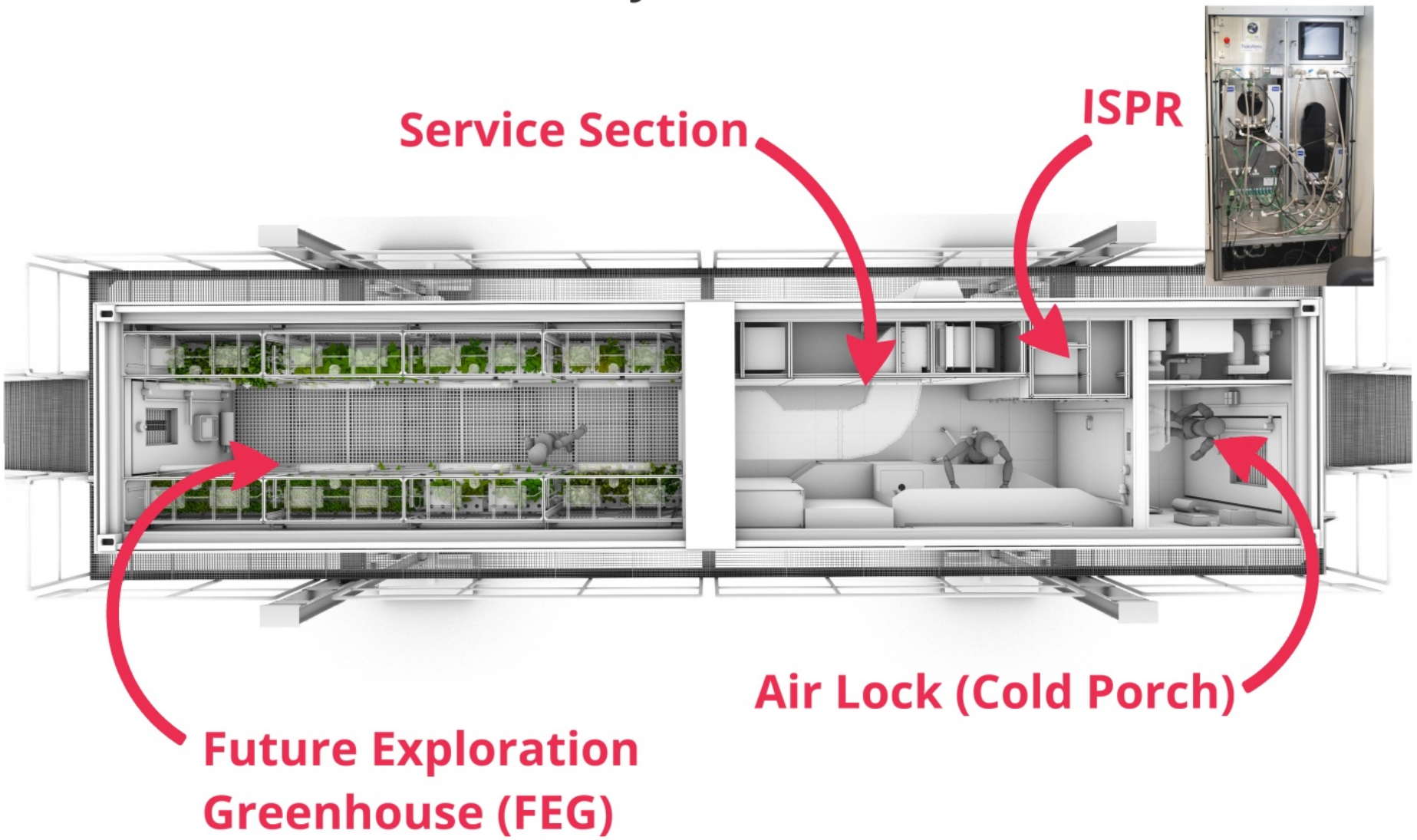
EDEN ISS - Research Facility



EDEN ISS - Research Facility



EDEN ISS - Research Facility

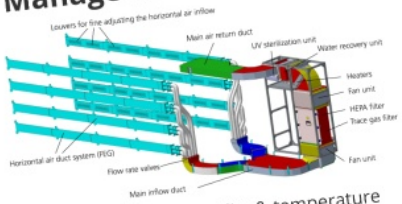


Key Facts:

- Completely insulated (~100mm)
- Total grow area: ~12.5 m²
- Closed-Loop System
- Controlled Environment Agriculture (CEA):

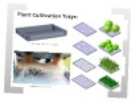
EDEN ISS

Air Management System (AMS):



- Exact control of humidity & temperature
- Active CO2 injection
- Complete water recovery
- Air purification (UV & HEPA & Carbon Filters)

Nutrient Delivery System (NDS):

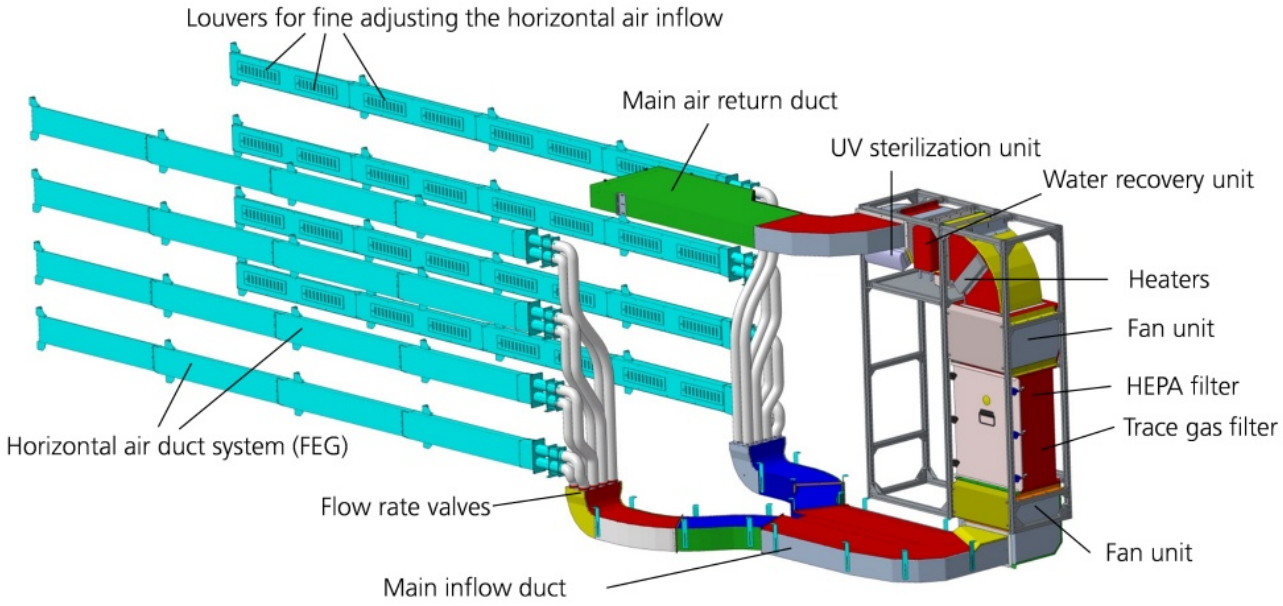


- Soiless cultivation (Aeroponics)
- Recirculation => no water loss
- Two irrigation solutions (leafy & fruity)
- Exact control of EC and pH value
- Active ozone injection

Illumination System (ILS):

- Exact control of light composition (r/b/fr/w)
- Extended illumination durations (18/6)
- Water cooled LED systems

Air Management System (AMS):



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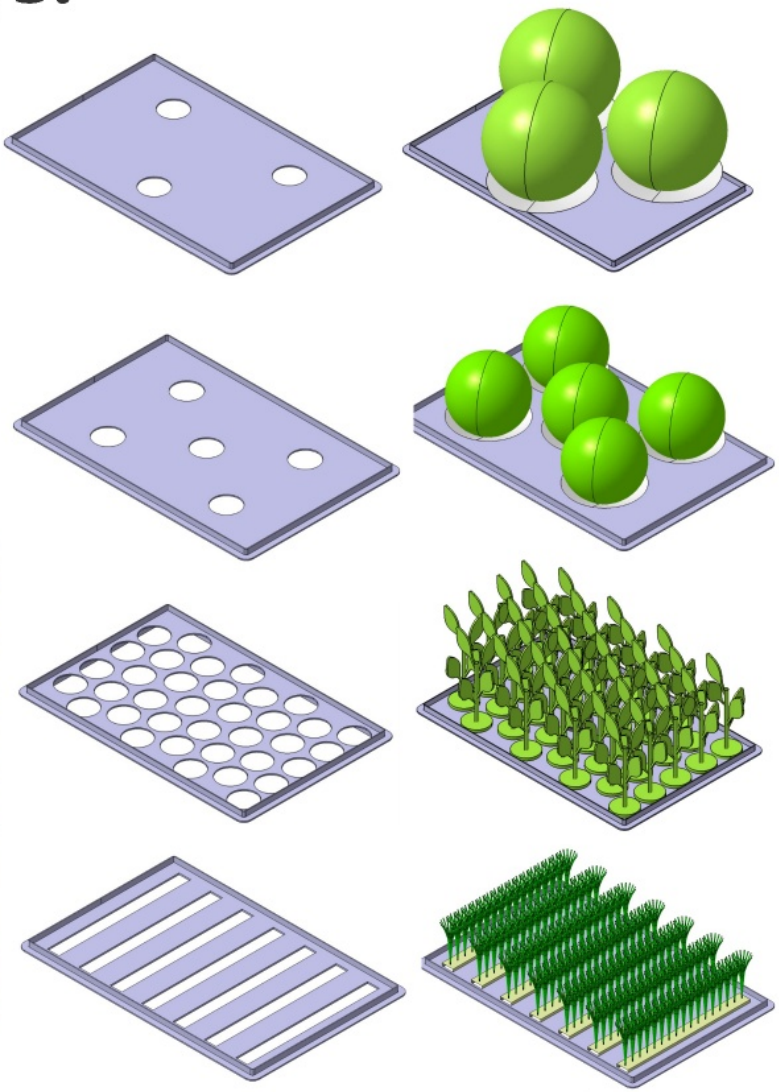
Plant Cultivation Trays:

Standard 'Euro': 40 x 60 cm

Areoponics within one tray



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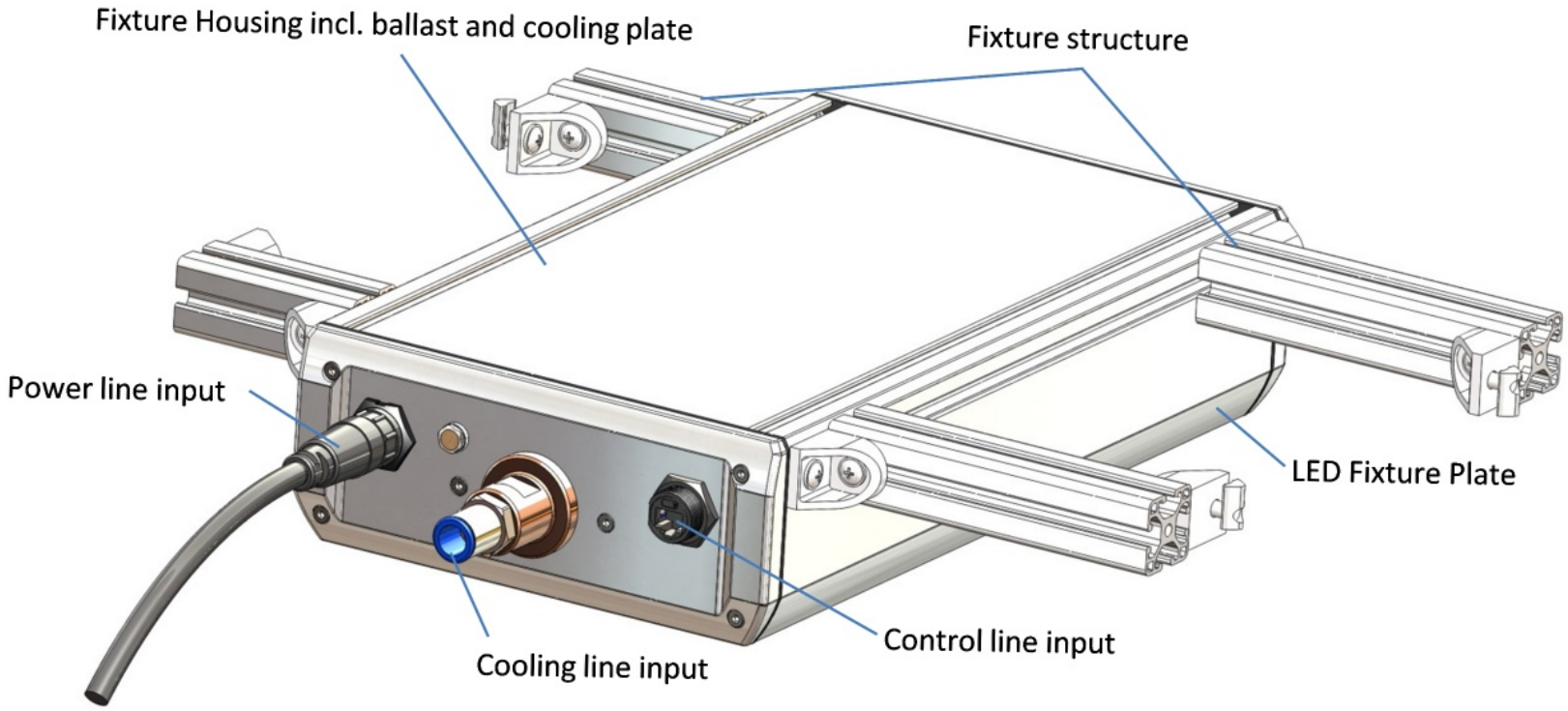

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EDEN ISS

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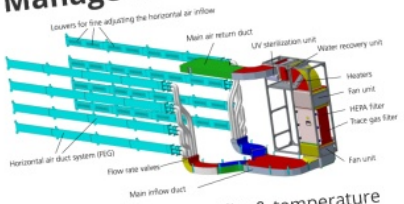

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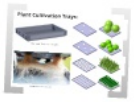

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Animation

Assembly, Integration & Test (AIT)

Construction of the EDEN ISS Greenhouse:

Containers during Spring 2016

Internal sub floor structure of the FEG

Water tanks

Containers after painting

Delivery of the Containers:

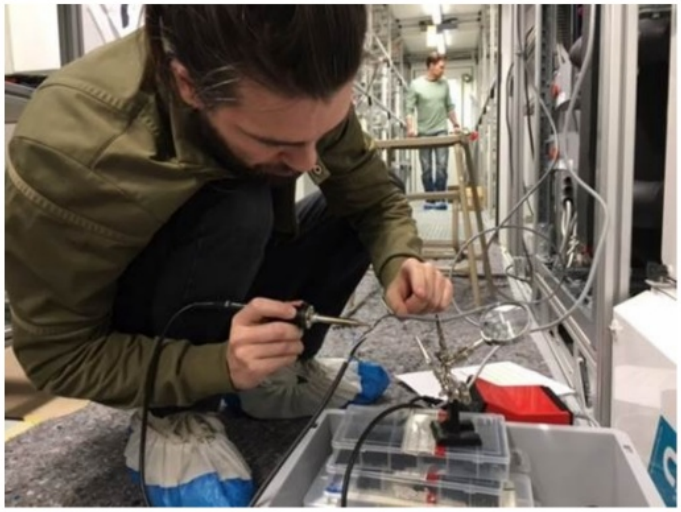
Containers arrive at DLR Bremen

Bringing the containers in position

Building the integration platform

Integration tent, connected to the Mobile Test Facility

Integration of Subsystems:



Connecting sensors, actuators to the main DHCS

TAS-I employees inside ISPR

CEA section built-up

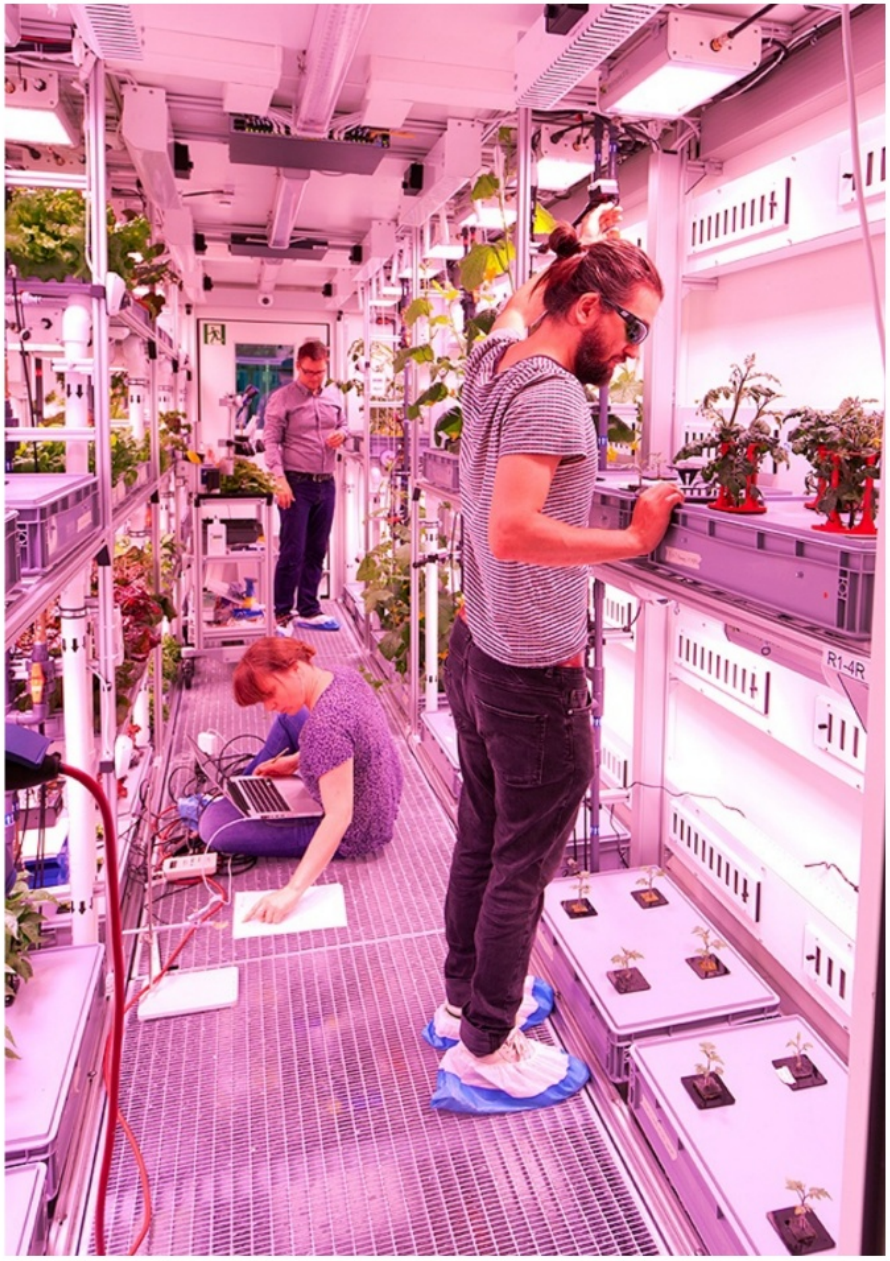
Busy day in the Service Section....

Assembly and integration completed

May/June 2017

EDEN ISS greenhouse system at the DLR Institute of Space Systems

Starting with a seed...



Work inside the FEG

Seedlings inside the nursery

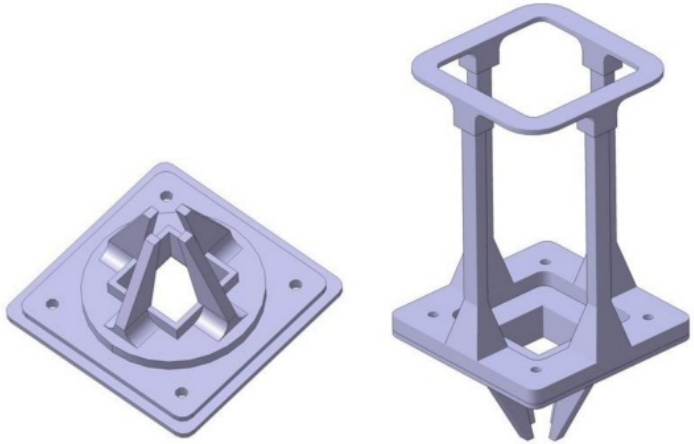
First lettuce inside the cultivation trays

… after 4 weeks.

All trays are planted with crops

Swiss chard plant tray

Tomato plant tray



3d-printed root plug holder

… after 12 weeks.

Fully developed canopy inside the FEG

Pepper

Tomato

Cucumbers

'Spiral' Grow Accommodation

Cucumber stems at the bottom of the grow position

… harvest day!

Pepper harvest

Lettuce harvest (Markus Dorn)

Swiss chard

Lettuce, cucumber, and radish

Students harvesting all crops of the FEG

Pepper harvest

Mission Prep. & Transport

August - October 2017

Final storage of spares & equipment inside the support container

South African research vessel in Cape Town

Container in Hamburg harbor

Cleaning the FEG

Final storage of spares & equipment inside the support container

Cleaning the FEG

port

South African research vessel in Cape Town

Container in Hamburg harbor

Deployment Mission

Dec. 2017 - Feb. 2018

How to get to Neumayer III?

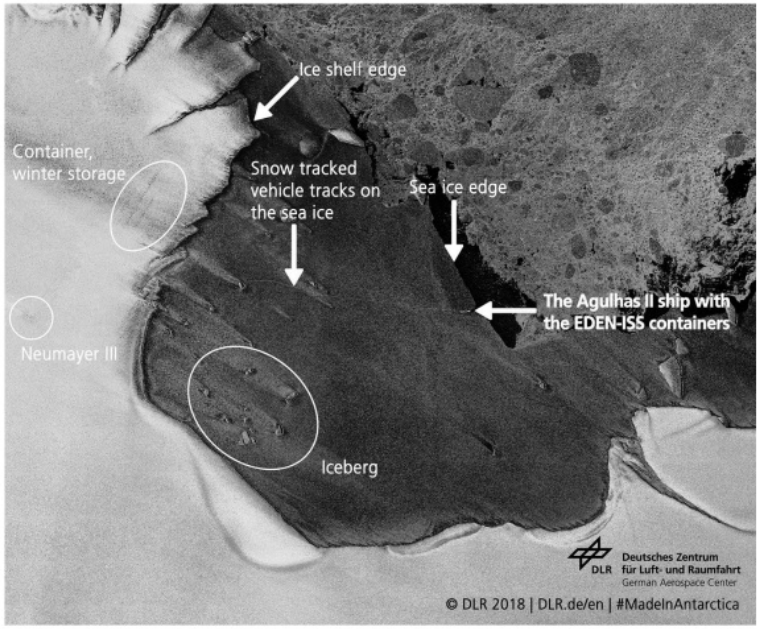
Arrival of crew in Dec. 2017 Novo Airbase

Connection flight to Neumayer III

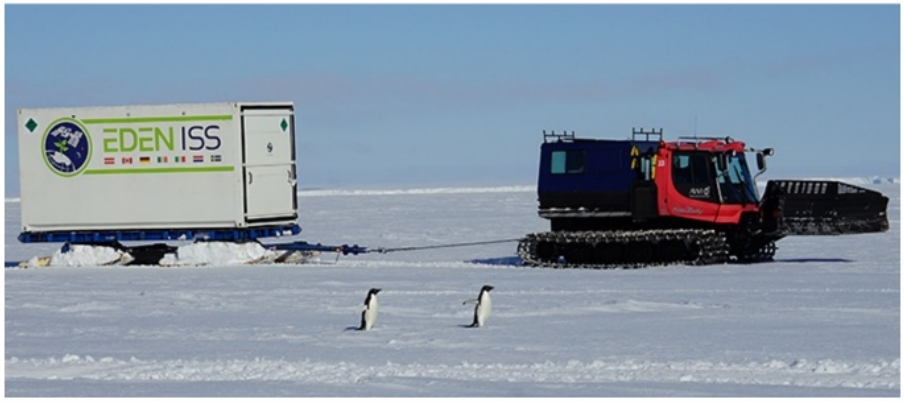
Off-loading the EDEN ISS Containers

South African research vessel Agulhas II delivered the containers

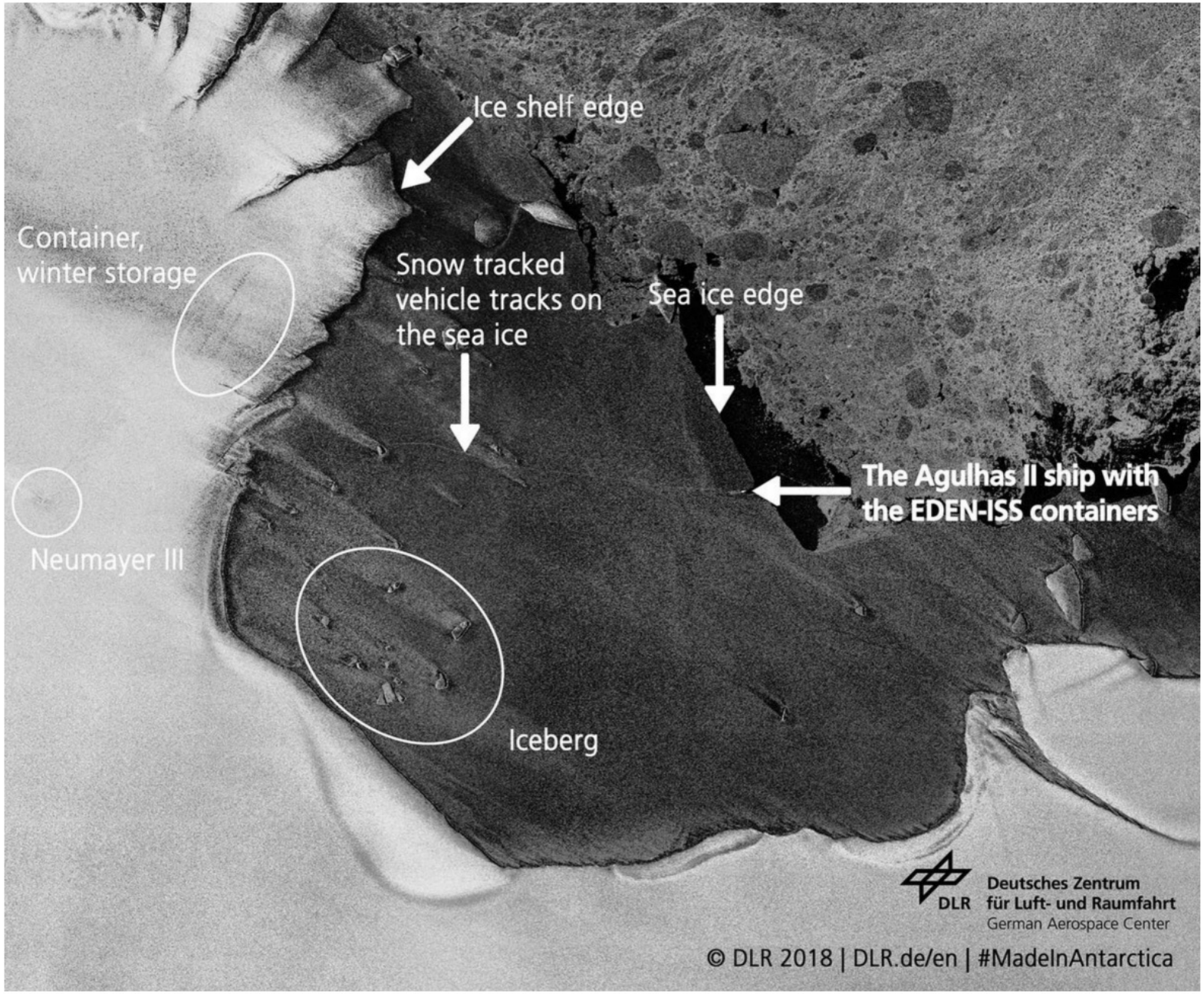
Agulhas II during off-loading



Satellite image during off-loading



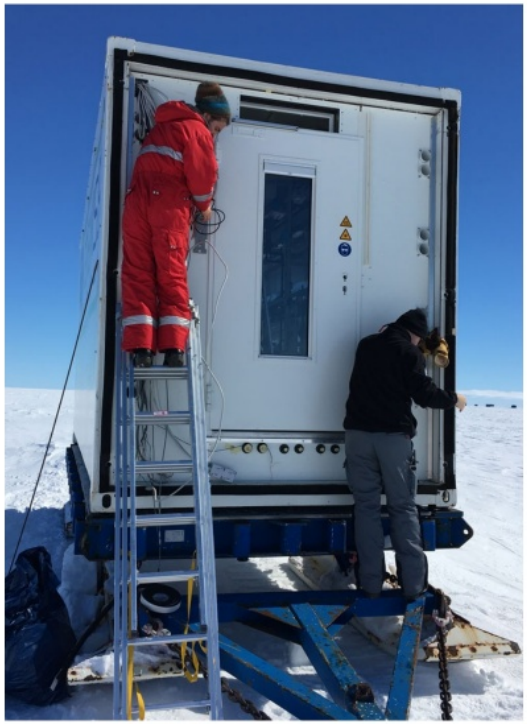
Transport of the EDEN ISS containers to NM-III



Satellite image during off-loading

EDEN ISS Integration

- Four weeks of subsystem integration
- Complete air duct, NDS and thermal control system piping interface connections
- External hardware installation
- Power & data connection to station
- Harness connection inside MTF



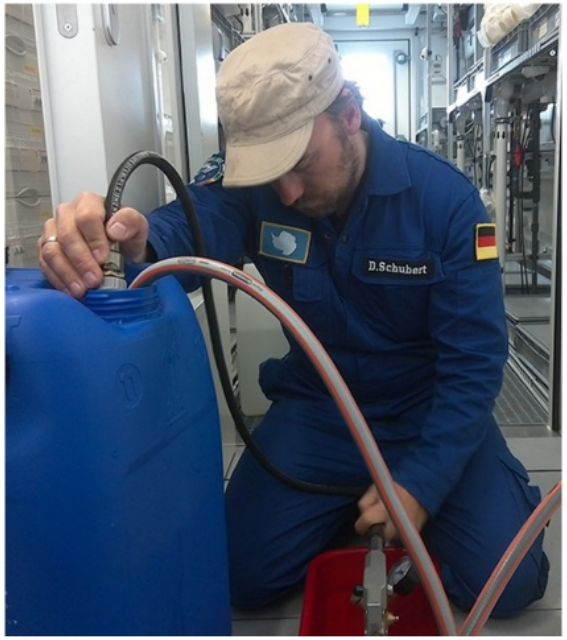
Interface preparation

Installing the EDEN ISS containers on the platform (400m away from the station).

Subsystem Integration

Installation and check-out of all CEA technologies

Bringing fresh water from the station



Pumping thermal fluid into the cooling unit

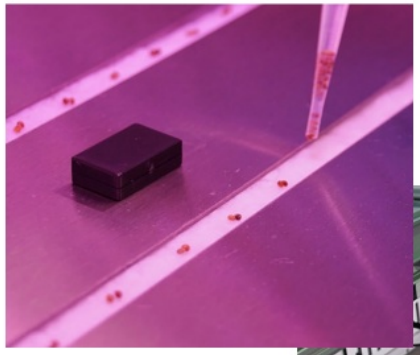
Filling the nutrient mixing tanks with water

Thermal insulation between the two containers

Subsystem Integration

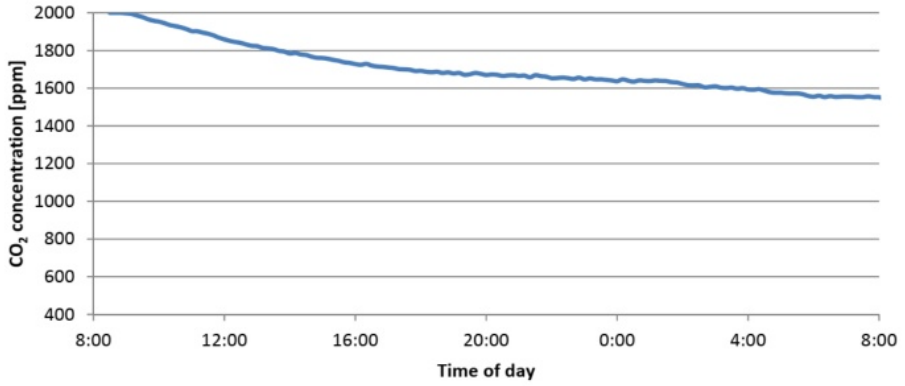
- Sensor calibration & check-out
- Establish data link to mission control (Bremen)
- CO2 leakage test within FEG
- Final clean-up of FEG
- Start with seedings the target crops

Cucumber plant inside the nursery of the FEG



Rocket seeds in the trays

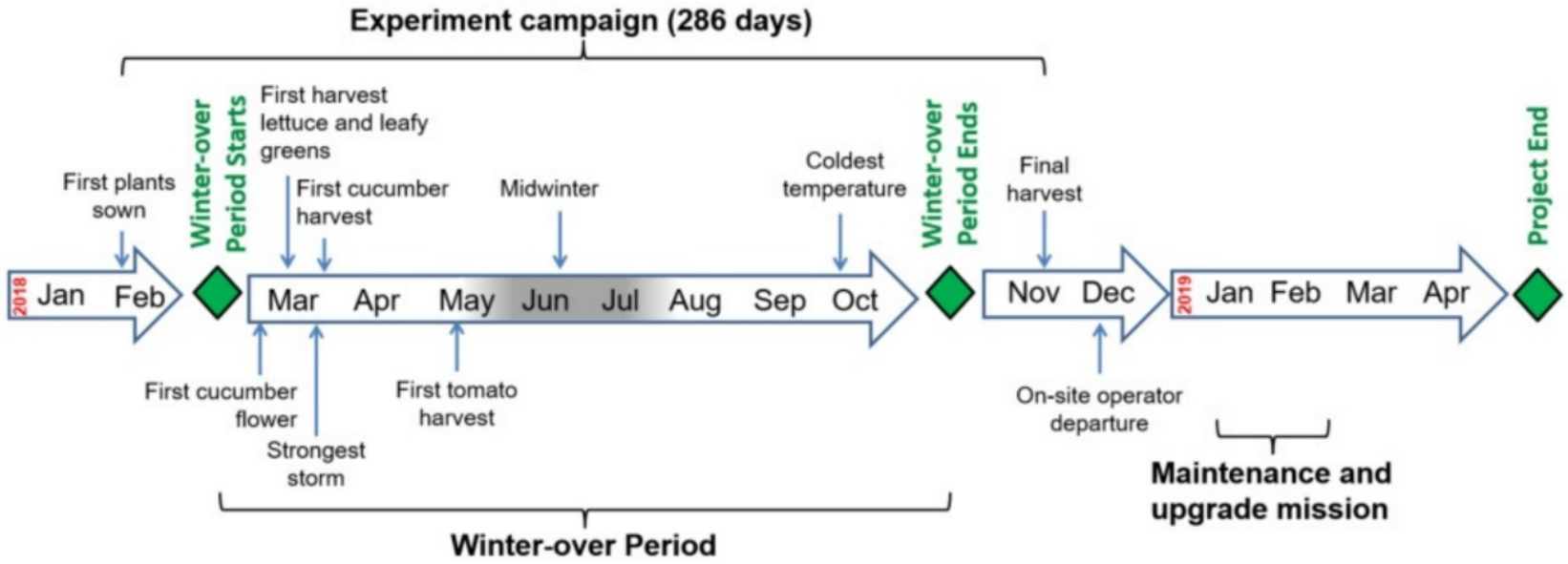
Anna-Lisa (UoF) seeding rocket seeds



CO2 concentration inside the FEG during the air exchange test with carbon dioxide as tracer gas

~Mid February 2018 the EDEN ISS was operational!

Experiment Phase



Start of Polar Night


March 2018
EDEN ISS

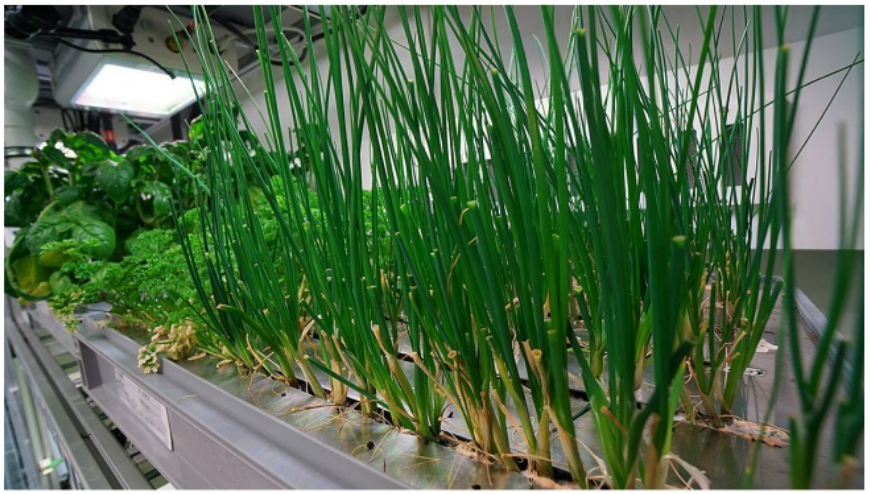

Mid April 2018
EDEN ISS


May 2018

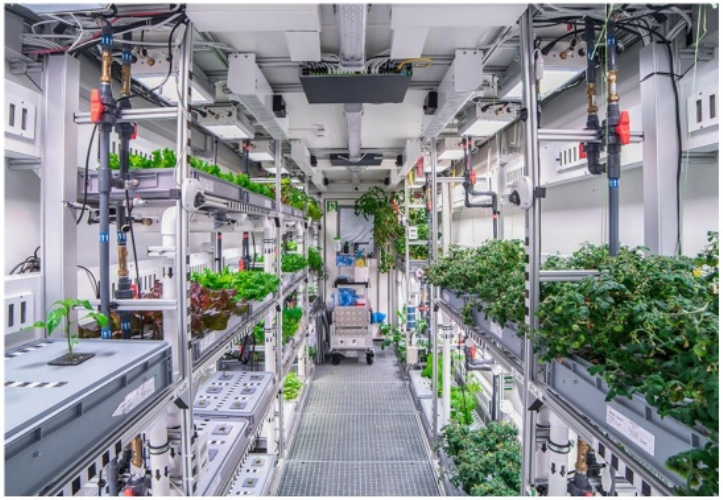

Mid June 2018
EDEN ISS
PLANT
CULTIVATION
TECHNOLOGIES
FOR SPACE

Continuous Production I

Four lettuce plant trays



Herbs (Chives, Parsley)



FEG during full operation mode

Cucumbers

Continuous Production II

Kohlrabi plant tray

Radish plant tray

Tomatoes plant tray

Swiss chard plant tray

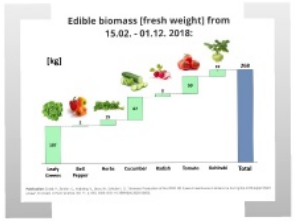
Edible Biomass

Paul during the first harvest

Tomato harvest

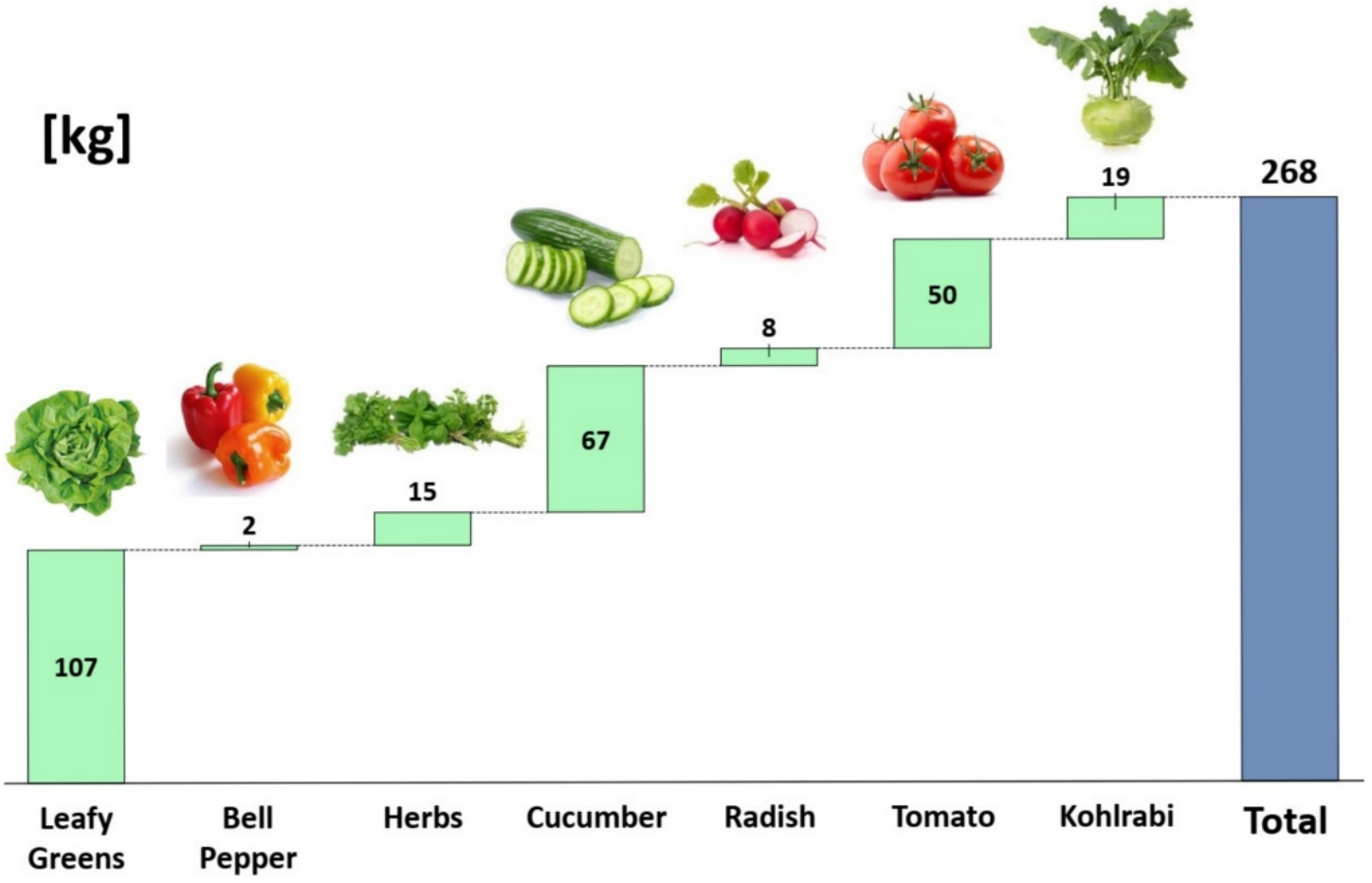
Pepper harvest

Lettuce harvest



Lettuce harvest

Edible biomass [fresh weight] from 15.02. - 01.12. 2018:



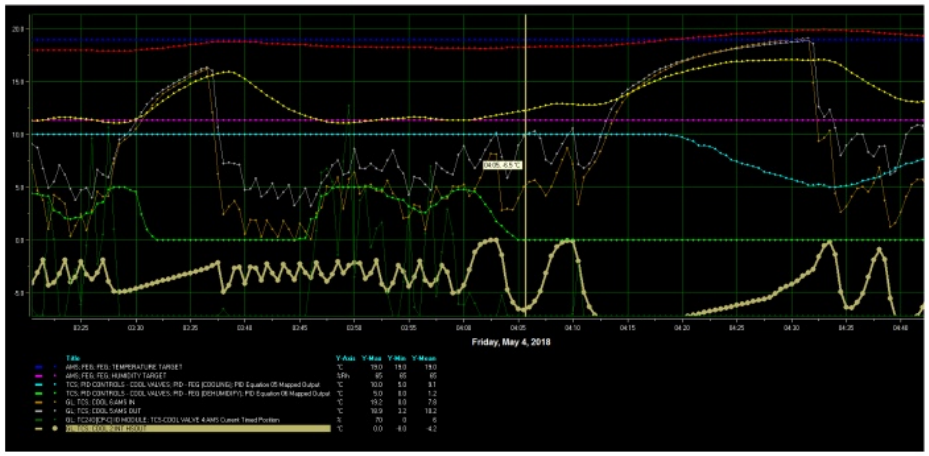
Publication: Zabel, P., Zeidler, C., Vrakking, V., Dorn, M., Schubert, D., "Biomass Production of the EDEN ISS Space Greenhouse in Antarctica during the 2018 experiment phase", Frontiers in Plant Science, Vol. 11, p. 656, 2020. DOI: 10.3389/fpls.2020.00656.

Film clip

Validation & System Test

- Technology testing and validation (AMS, ILS, NDS, TCS)
- Testing and improving the operation procedures
  - For critical systems only
  - Generation of a plant treatment handbook

Mission Control Center @ DLR



24h data log of key parameters (ARGUS Control)

Food Quality & Safety

- Nutritional investigations
- Nutritional Quality Analysis Protocols
- Sensory panel
- Safety quick tests
- Over 30 food samples for later analysis (publication in process)

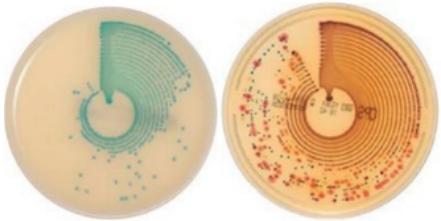
Refractometer (Sugars)

SPAD Meter (Chlorophyll)

Paul Zabel perfoming FQS tests in the station

Penetrometer (Firmness / Ripeness)

Colourimeter (Ripeness / Bioactives)



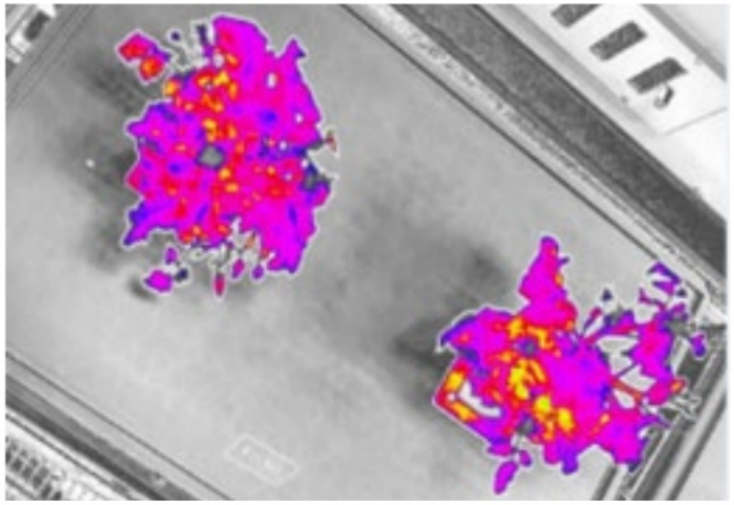
Bio Merieux (ChromID® media)

Ready-to-use vials

Nitrate Meter (Antinutritional)

Plant Health Monitoring

- Plant observation via 34 cams
- One picture a day of each tray
- Analysis program for health monitoring
- 2 x mobile spectral imaging cams



Multi-wavelength image of Tomato plants (UF)

Observation Cams

Top view (lettuce)

Side view (Tomato)

Publications: Zeidler, C.,et al (2019) "The Plant Health Monitoring System of the EDEN ISS Space Greenhouse in Antarctica During the 2018 Experiment Phase", Frontiers in Plant Science, Vol. 10, p. 1457, 2019. DOI: 10.3389/fpls.2019.01457, ISSN 1664-462X.
Tucker, R., et al. (2020) NDVI imaging within space exploration plant growth modules - A case study from EDEN ISS Antarctica. Life Sciences in Space Research, 26, Seiten 1-9. Elsevier. DOI: 10.1016/j.lssr.2020.03.006, ISSN 2214-5524.

Microbial Investigation

- Monthly surface sampling (15 locations & 10 corps)
- Monthly liquid sampling of nutrient solution & fresh water
- Sample return mission Dec. 2018 (samples at -40°C)
- E-nose testing on plants & surfaces (Airbus D&S)

Sample taking in the FEG

Microbial load of crops were **1000 times smaller** than crops from supermarket

Microbial environment inside greenhouse varies over time

E-Nose

E-nose on plant tray

Publication: Fahrion, J., Fink, C., Zabel, P., Schubert, D., Mysara, M., van Houdt, R., Eikmanns, B. J., Beblo-Vranesevic, K., Rettberg, P. (2019) "Microbial Monitoring in the EDEN ISS greenhouse, a mobile test facility in Antarctica", Frontiers in Microbiology, Vol. 11, Article 525, 2020.

Psychological Investigation

- Seven months of isolation
- Two dedicated questionnaires (DLR-ME)
- Target group discussion

38th Neumayer III overwinterinmg crew

Publication: Schlacht, I. L., Kolrep, H., Schubert, D., Musso, G., "Impact of plants in isolation: The EDEN-ISS Human Factors investigation in Antarctica" in Advances in Human Factors of Transportation, Springer Verlag, 2019; pp. 794-806, Advances in Intelligent Systems and Computing book series (AISC, volume 964).

Outreach & Education

- Social media via Facebook, Instagram, Youtube
- Teaching materials for schools
- Live lectures from Antarctica
- Art competition & Seed campaign
- Live Grow Monitor

Dedicated experiment tool kit for children

Children's art competition

Seed Campaign during Antarctic Mission

Publication: Zabel, P., Zeidler, C., Vrakking, V., Schubert, D., Imhof, B., Hogle, M., "Summary and Evaluation of the EDEN ISS Public Outreach Activities", International Conference on Environmental Systems, 2020.

Present & upcoming Projects

NASA Mission 2021

Second Analogue Mission:

- DLR-NASA Collaboration
- NASA scientist overwintering
- Science program with ~ 10 different experiments
- Test of dedicated plant cultivation system, based on VEGGIE system

Jess Bunchek working on the VEGGIE plant cultivation system at NASA

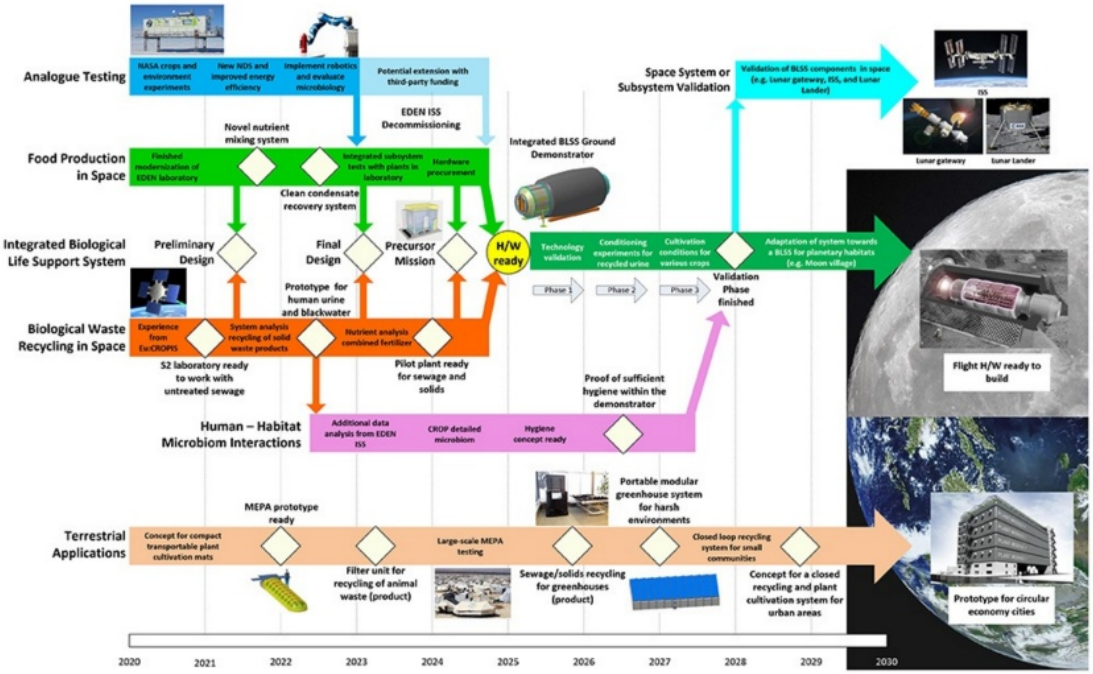
Jess Bunchek (NASA)

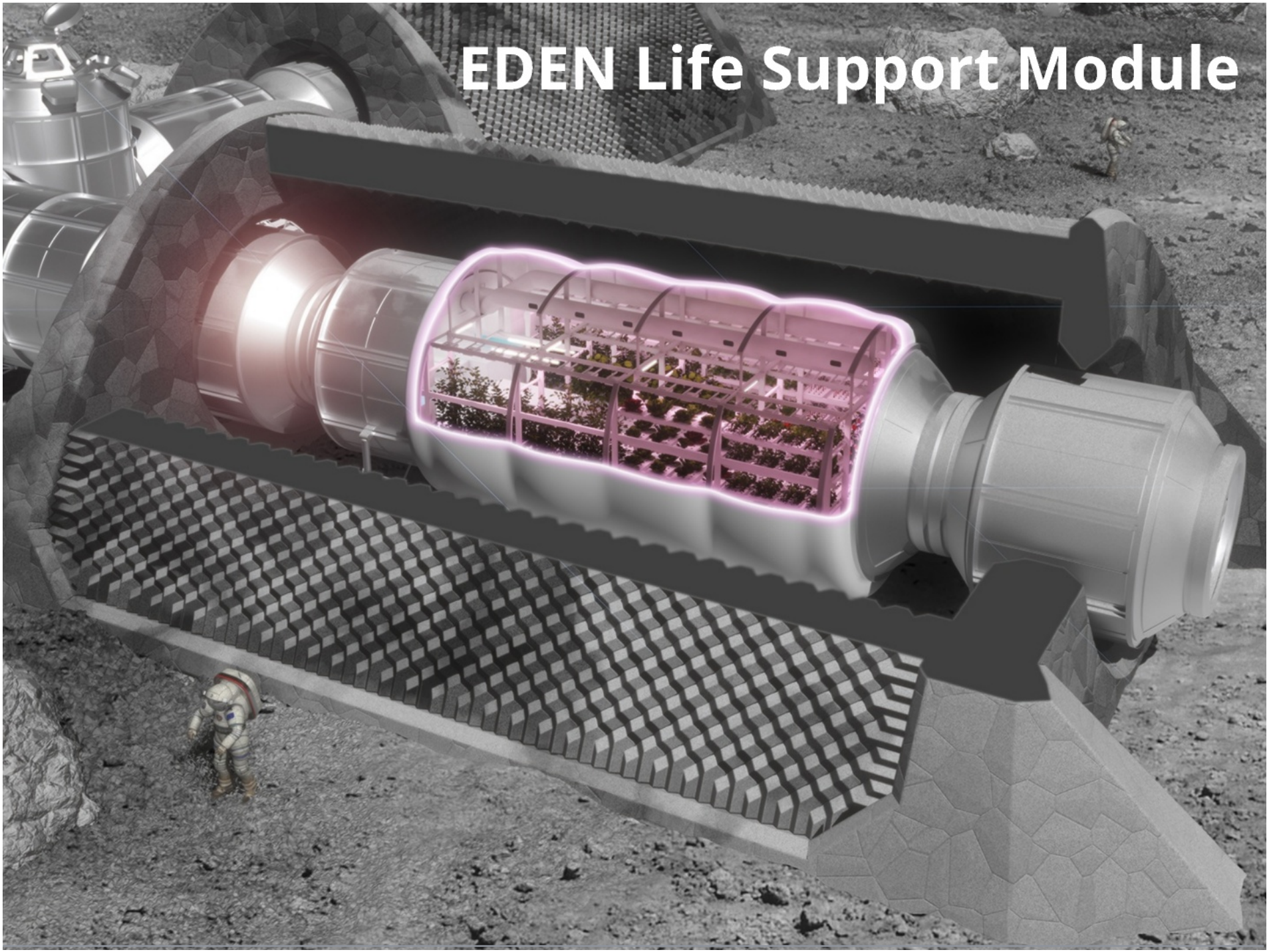
DLR Life Support Module

- *'Roadmap zur Entwicklung bio-regenerativer Lebenserhaltungssysteme im DLR'*
- Internal DLR development strategy
- Multiple DLR institutes involved

Goal: Development of space-ready design of lunar greenhouse by (~)2025

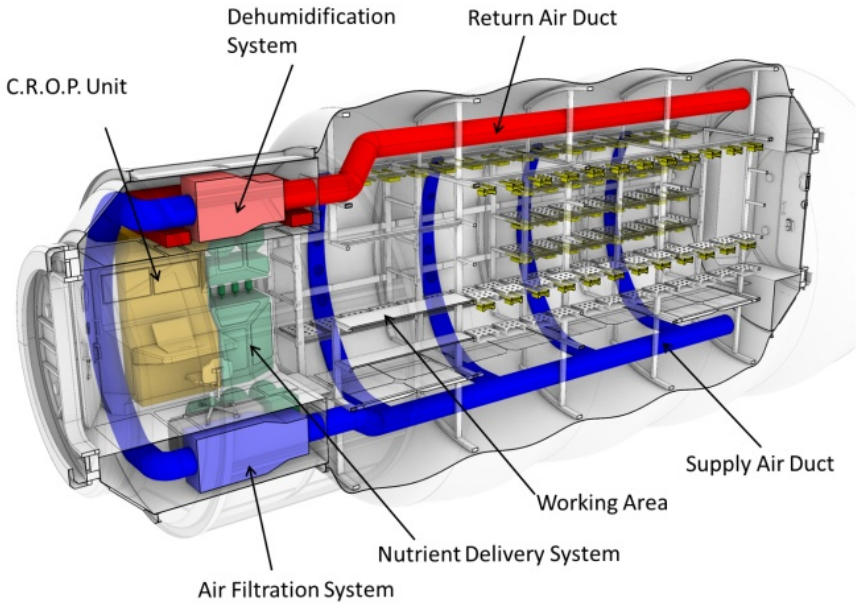
DLR Roadmap (published Spring 2020)

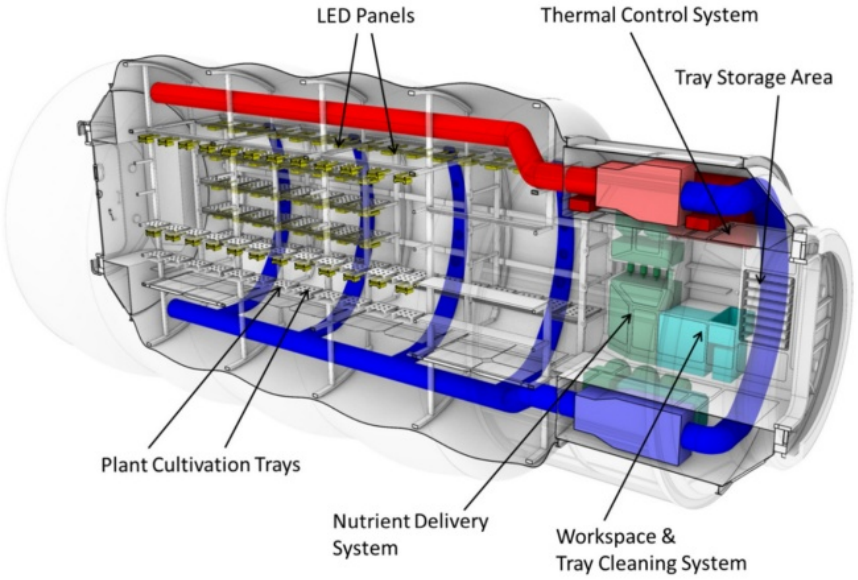



EDEN Life Support Module

DLR Life Support Module

- 30 m² cultivation area
- 90 kg fresh food per month (0,5 kg per crew member/day*)
- Urine processing & solid waste recycling
- Recycling of water
- Revitalization of cabin air (CO2=>O2)

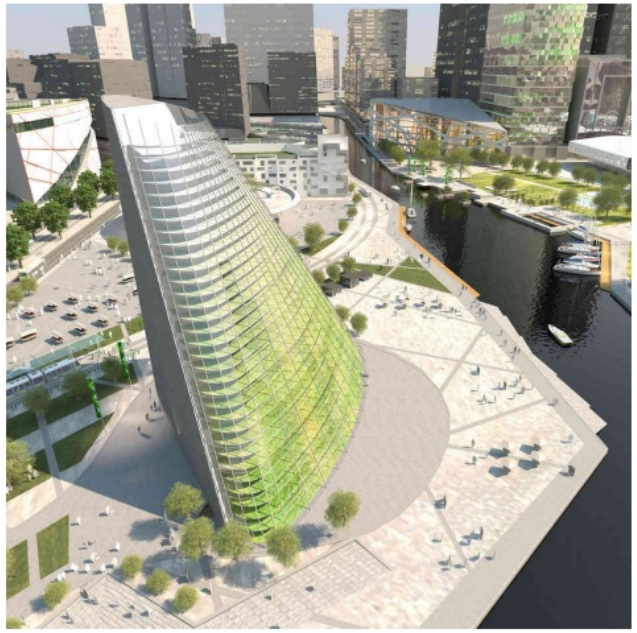




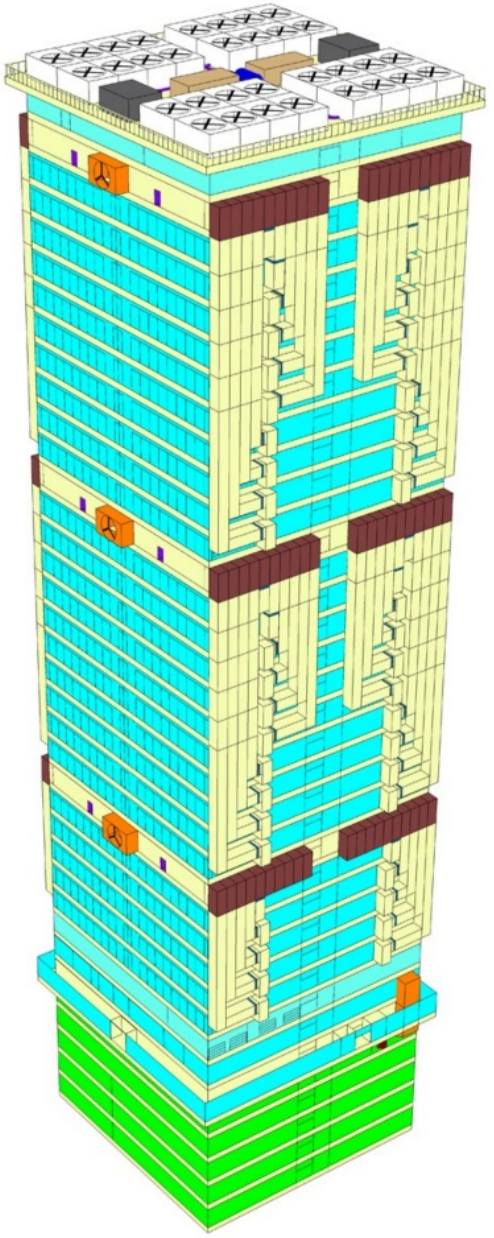
*for a crew of 6 members

Animation

Terrestrial Applications



Vertical Farming



DLR Vertical Farm Concept

(Source: Ozu Corporation in Tokyo, Japan, 2009)

(Source: Sky Greens vertical farm, Singapore, 2017)

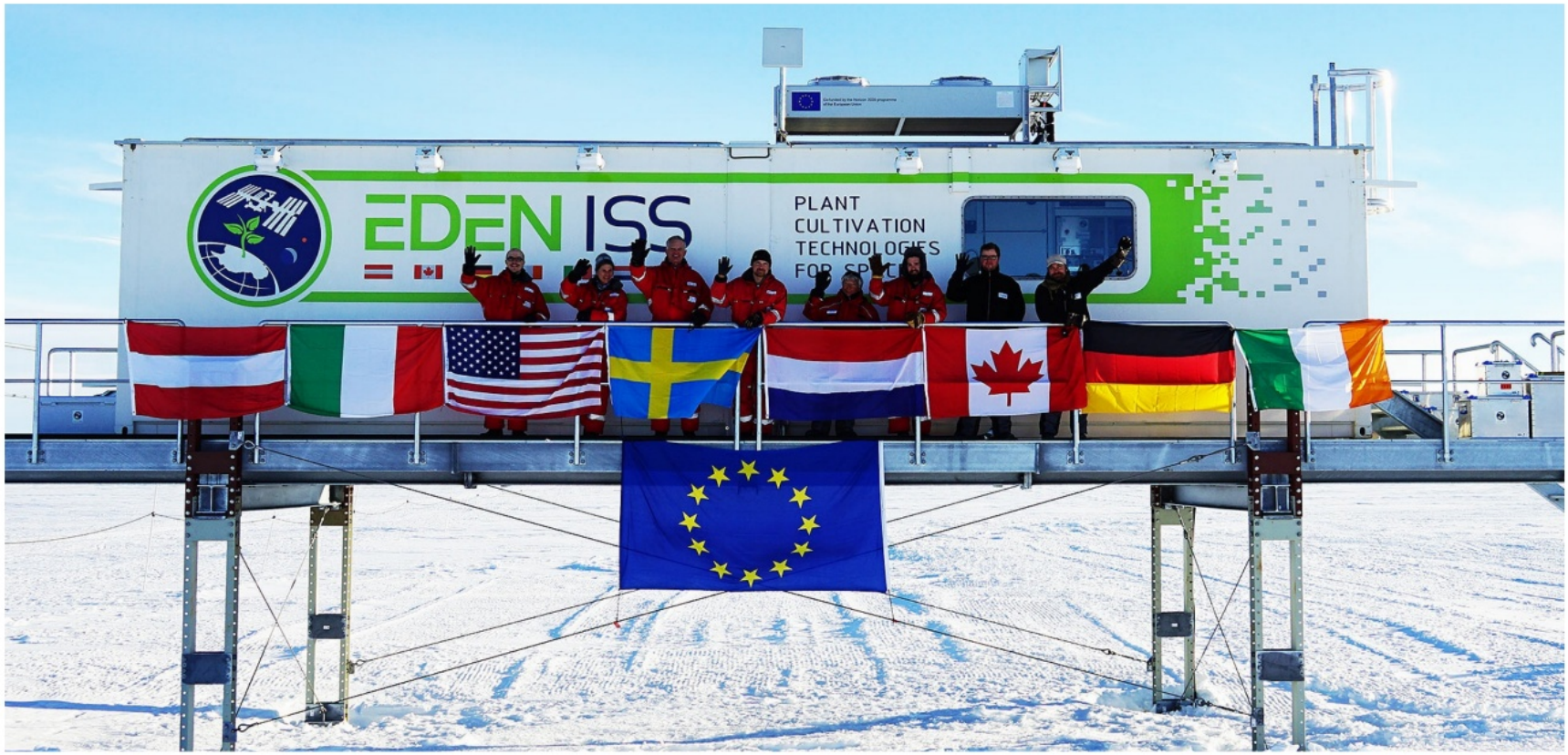
(Source: Shigeharu Shimamura, Japan)

(Source: Innovatus Inc., Japan, 2016)

Conclusion

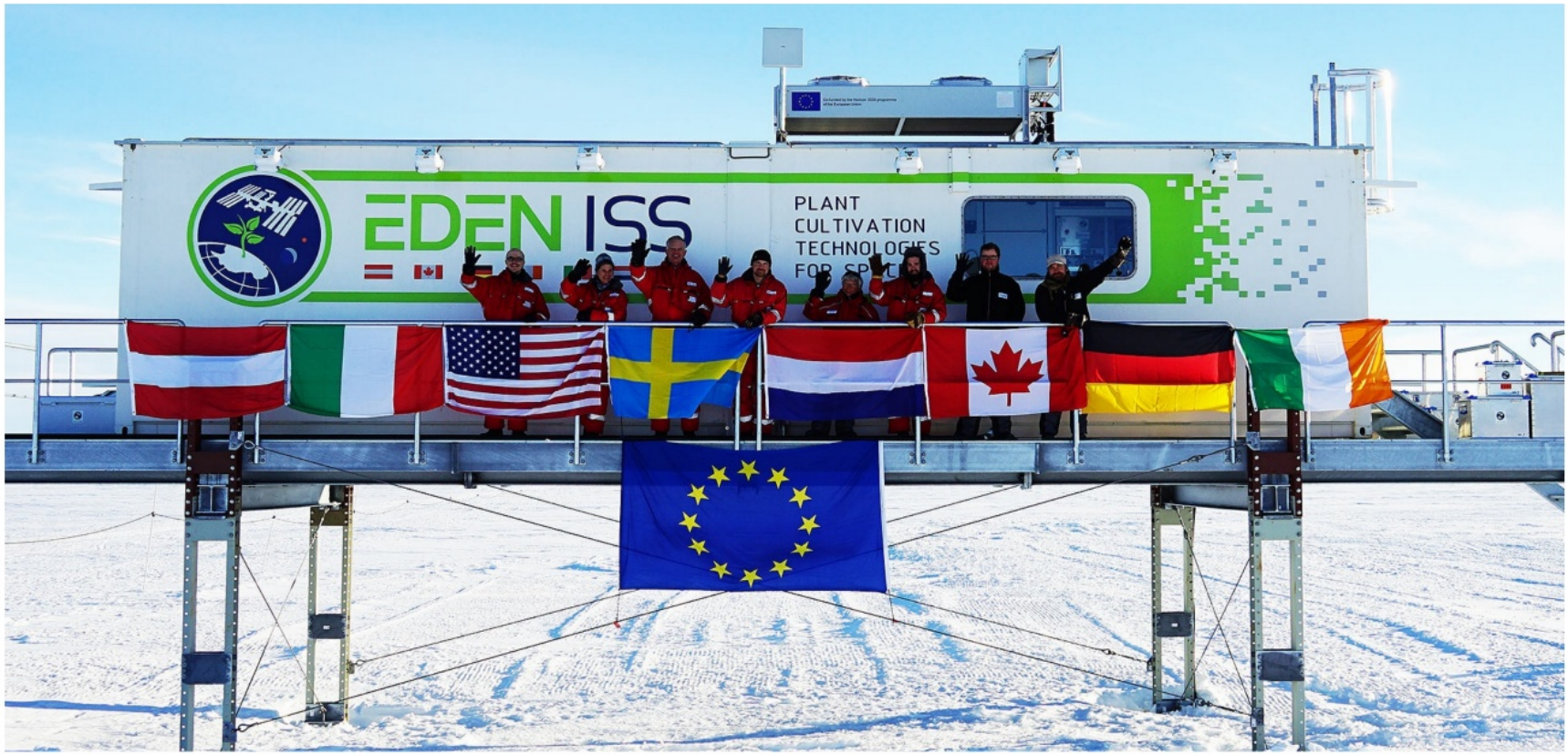
Conclusion

- EDEN ISS: Plant cultivation technologies for space



Conclusion

- EDEN ISS: Plant cultivation technologies for space
- One year analogue testing @ NM-III (Antarctica)



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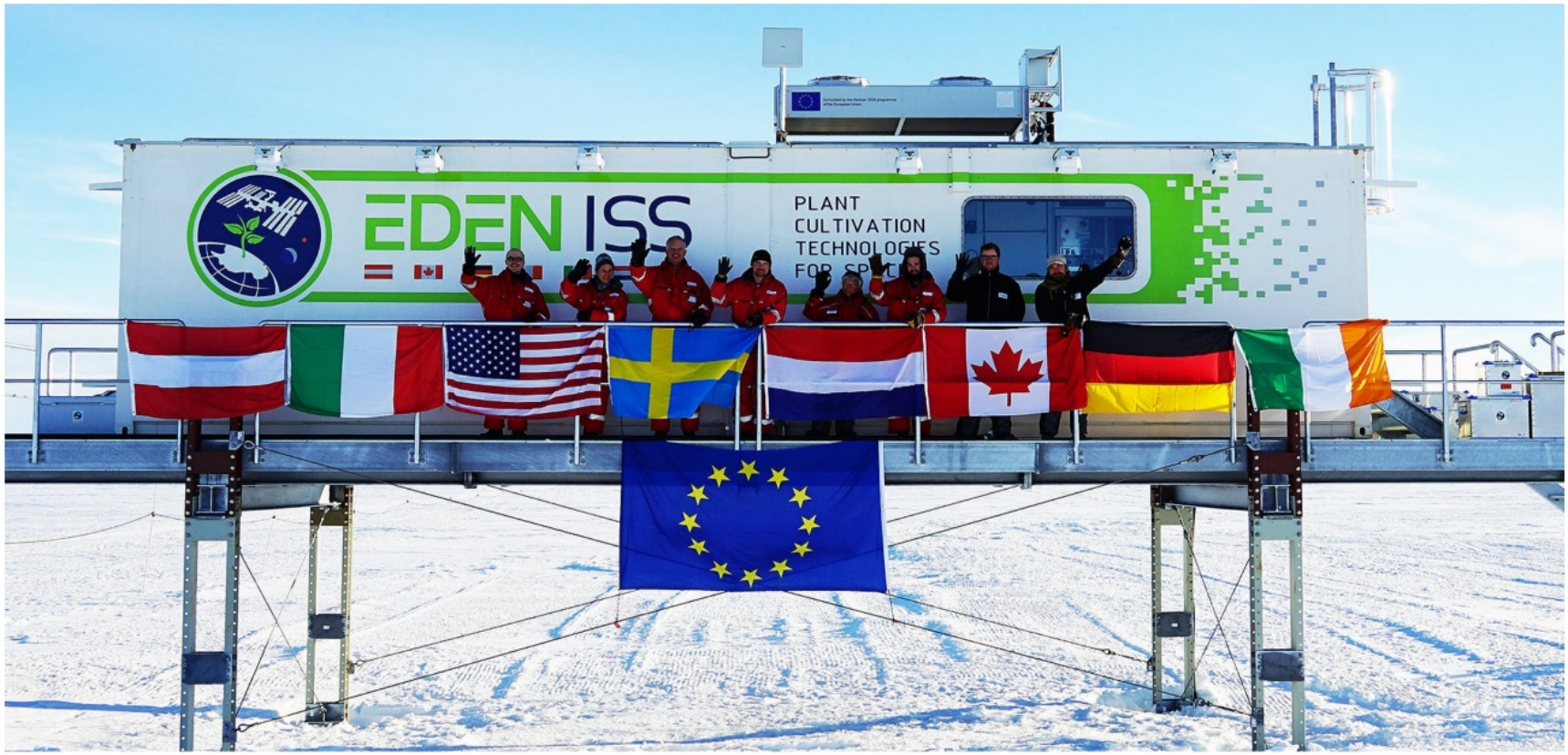
- Technology- & operation testing (~40 Tests)



Conclusion

- EDEN ISS: Plant cultivation technologies for space
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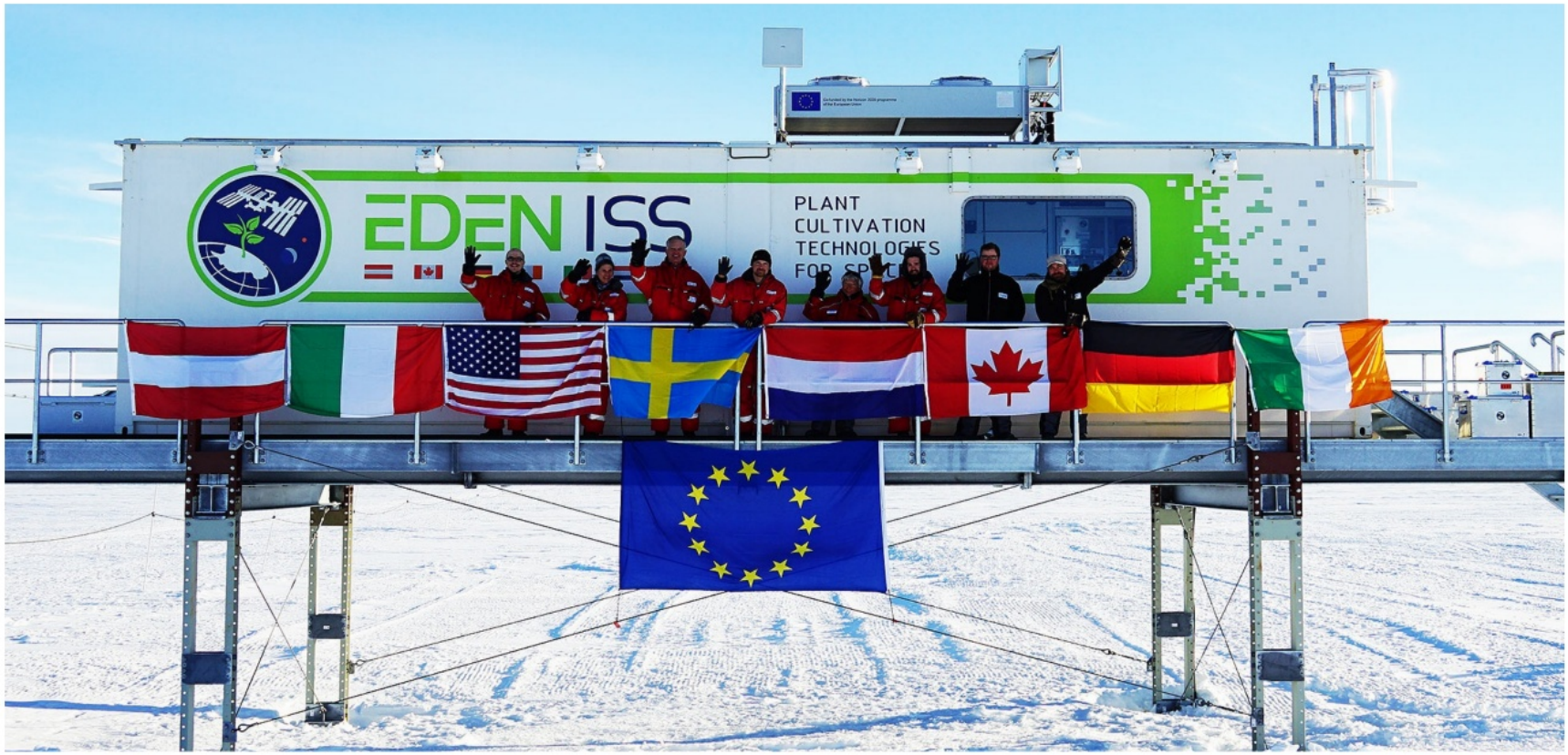
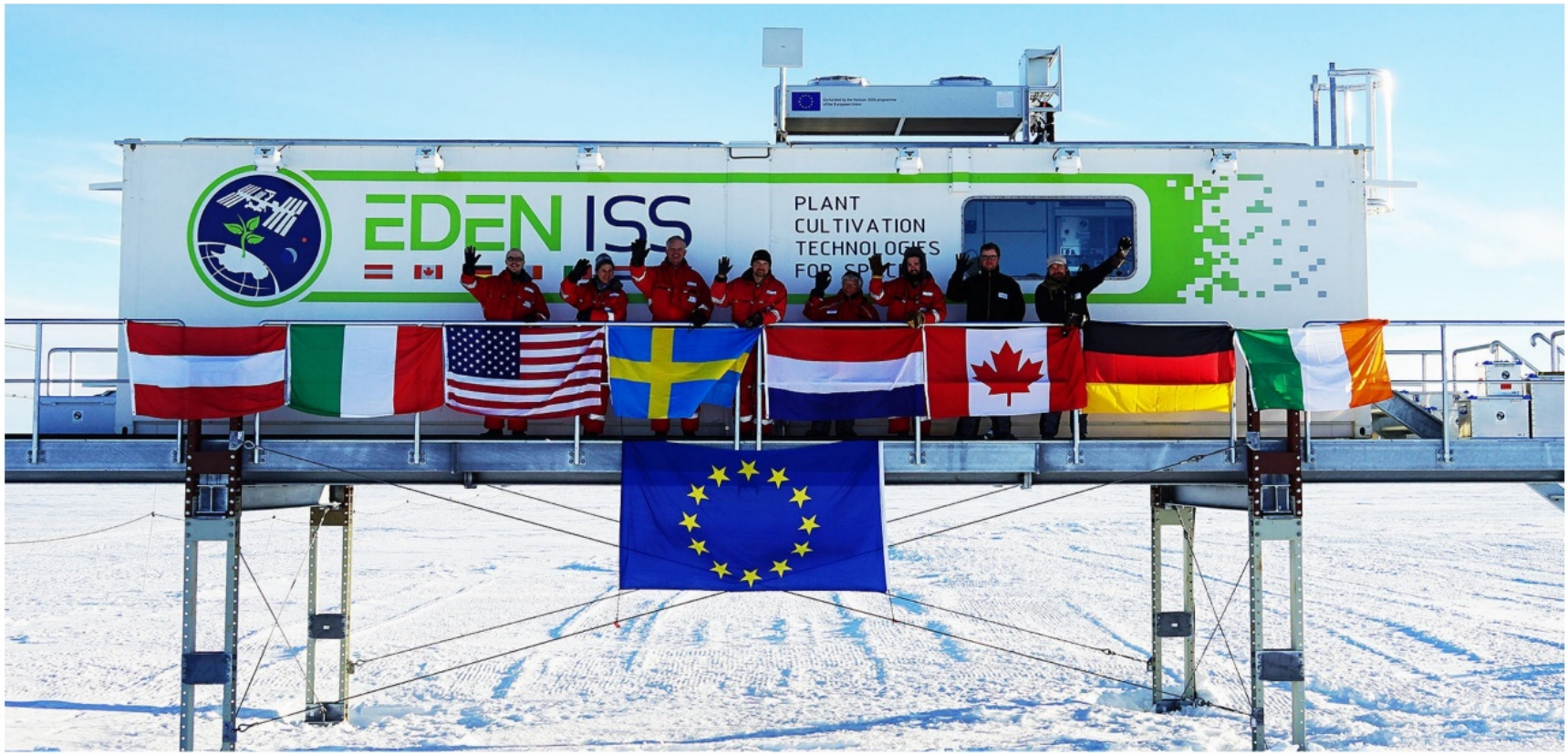
- Operation is ongoing for the next years. Open for scientists!



Conclusion

- EDEN ISS: Plant cultivation technologies for space
- One year analogue testing @ NM-III (Antarctica)
- Technology- & operation testing (~40 Tests)
- Operation is ongoing for the next years. Open for scientists!
- Future plan: Integrated life support module (DLR Roadmap)




Thank you for your Attention!
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