

EDEN ISS

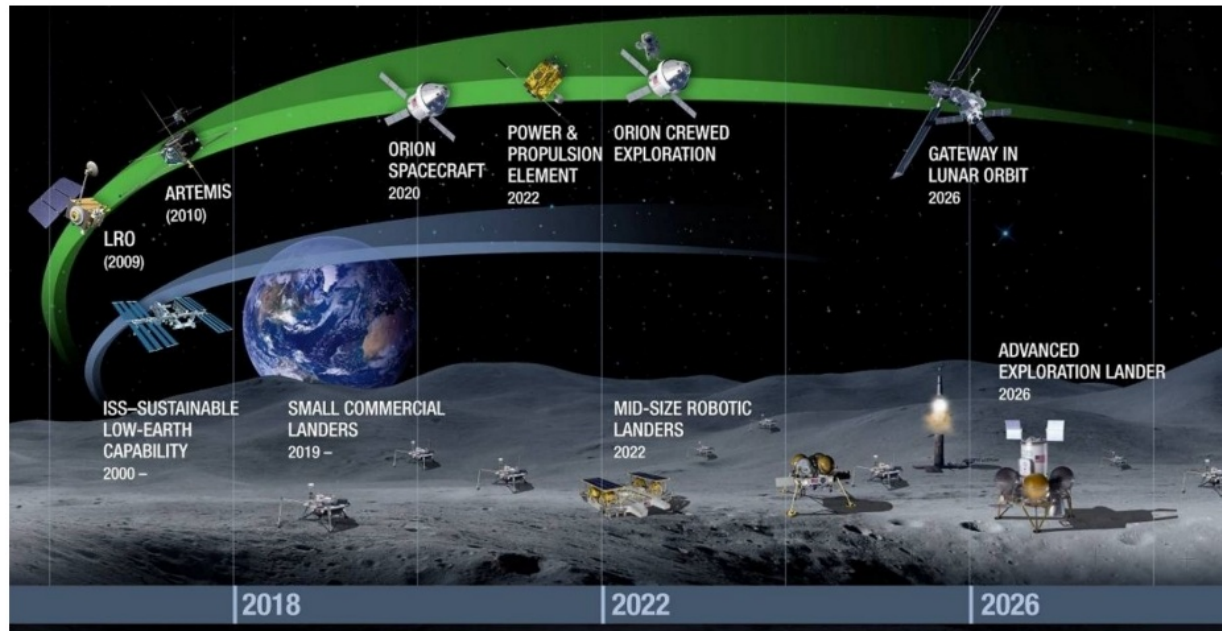
ANALOGUE TESTING OF PLANT CULTIVATION TECHNOLOGIES FOR SPACE

Dr. Daniel Schubert, Institute of Space Systems

6th of December 2022



Future Human Outposts on Moon and Mars

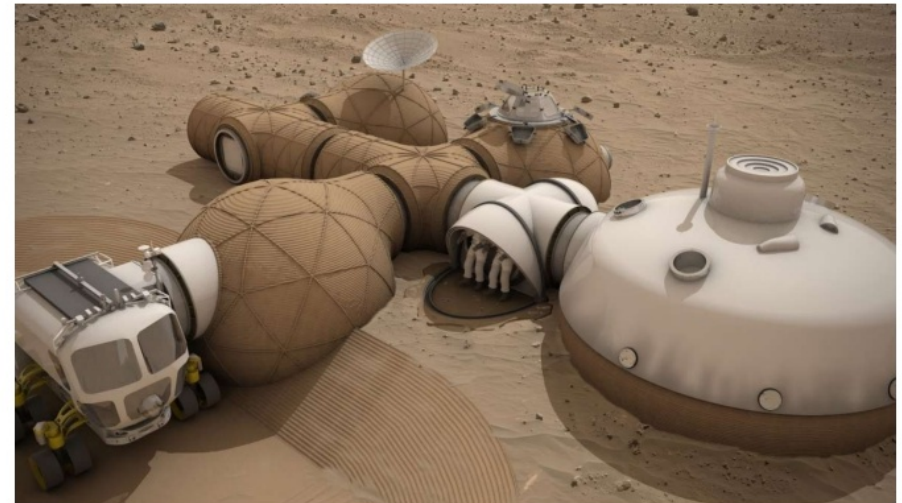


- Humans return to the Moon by this decade (NASA Artemis program)
- Human long-duration presence on Moon and Mars eventually
- Steady resupply of consumables necessary!

ARTEMIS Roadmap of NASA for the return of humans to the surface of Moon [Source: NASA]



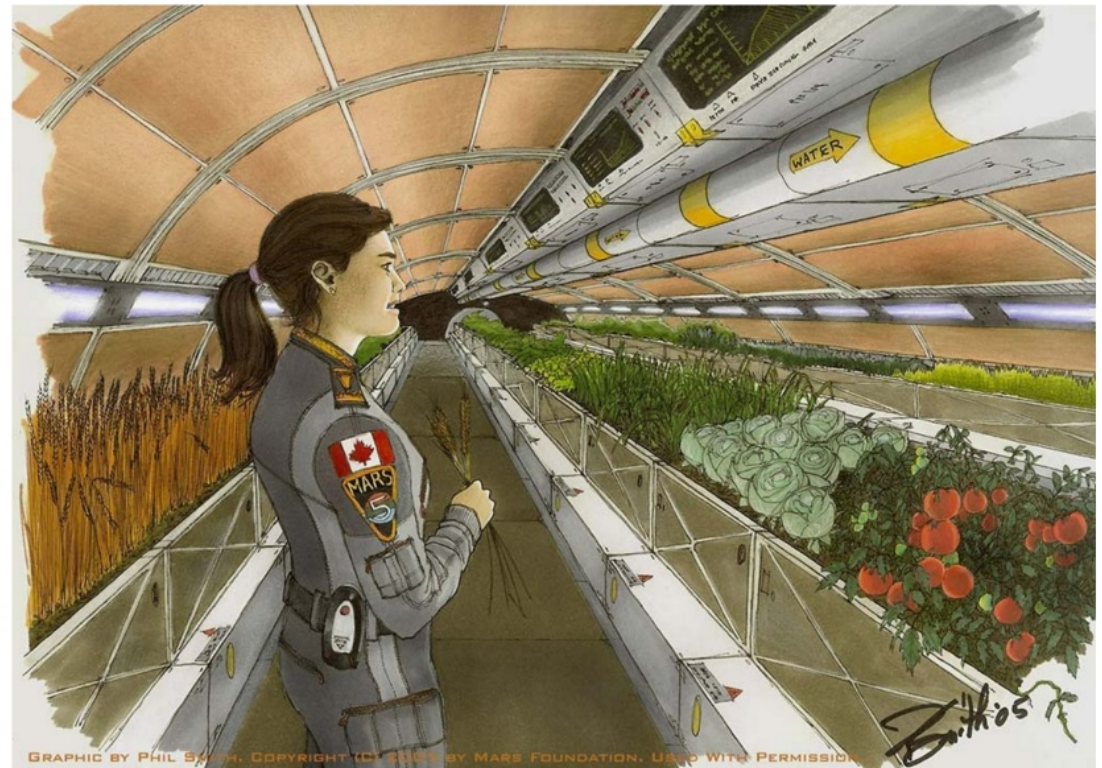
Moon habitat concept: ZARM (2018)



Mars habitat concept: Lava Hive Concept (2015)

Greenhouse modules as an infrastructure element of habitats

Artist Impressions



Why Plants?

Greenhouse modules as an infrastructure element of habitats



Fresh Food



**Atmosphere
Revitalization**



Water Recycling



Well-Being



NASA Food Production Facility Concept (2015)

Greenhouse modules as an infrastructure element of habitats



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NASA Food Production Facility Concept (2015)

Antarctic Greenhouse System

Analogue Testing of Plant Cultivation Technologies

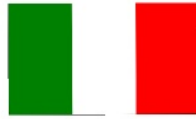


EDEN ISS



- 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





Why Analogue Testing in Antarctica?

Analogue Testing at Neumayer Station III

Similar Challenges than on Moon or Mars

- Similar crew size
- Isolation & resupply once a year
- Harsh environment
- Technology dependency



Initial Target Plants:



Lettuce



Red Outrageous Lettuce



Rucola



Spinach

[...]



Tomato



Pepper



Cucumber



Radish

[...]



Strawberry



Different Herbs

[...]

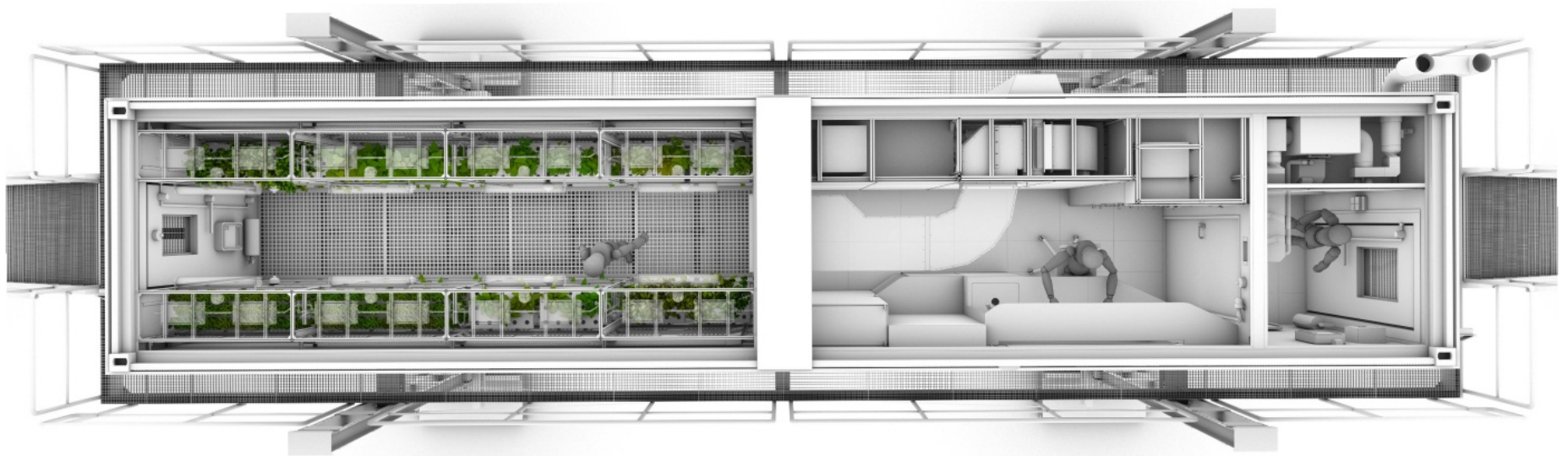
[fresh weight values]

EDEN ISS - Research Facility

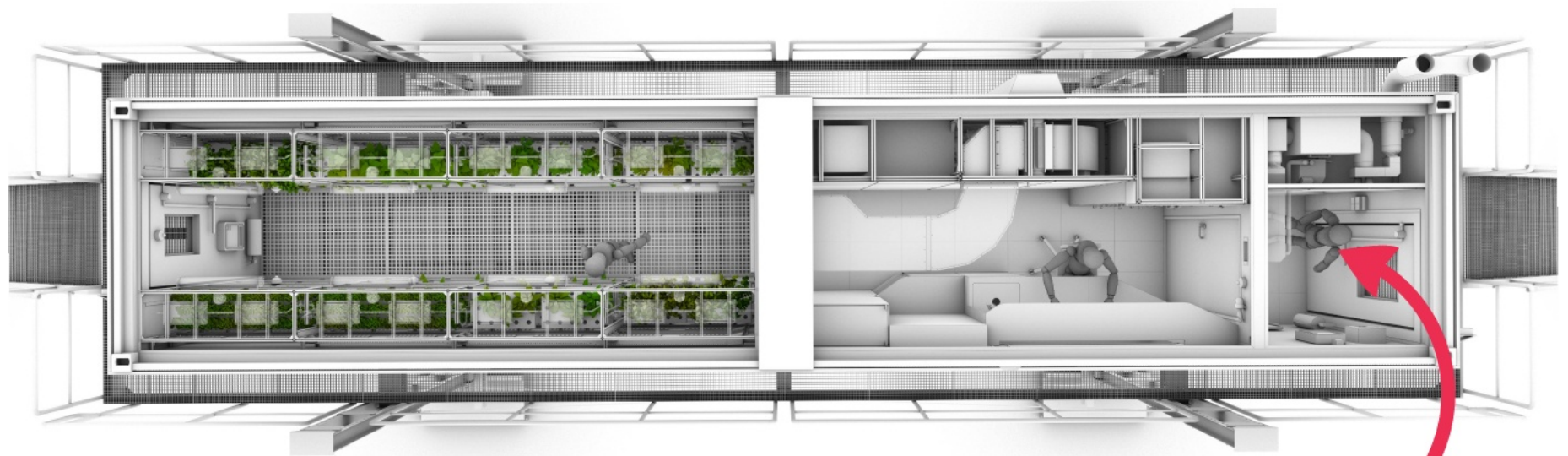


- Completely insulated (~100mm)
- Total grow area: ~12.5 m²
- Closed-Loop system

EDEN ISS - Research Facility



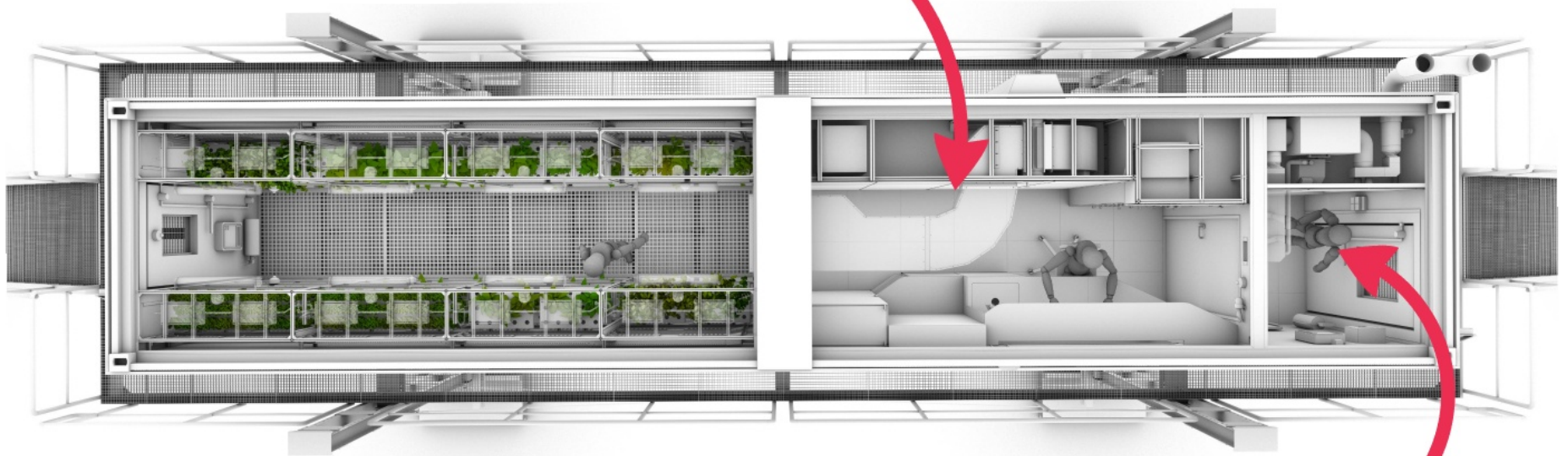
EDEN ISS - Research Facility



Air Lock (Cold Porch)

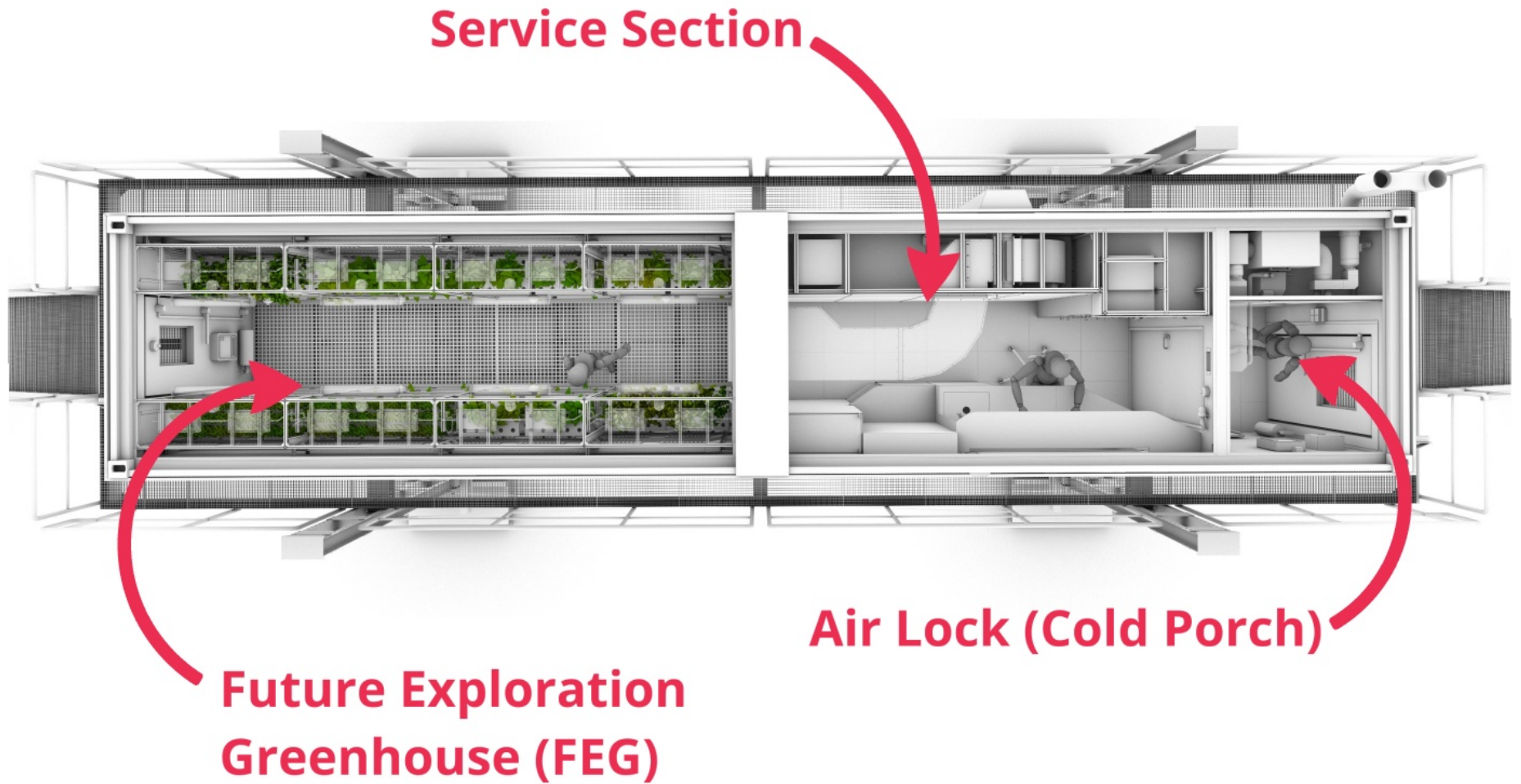
EDEN ISS - Research Facility

Service Section

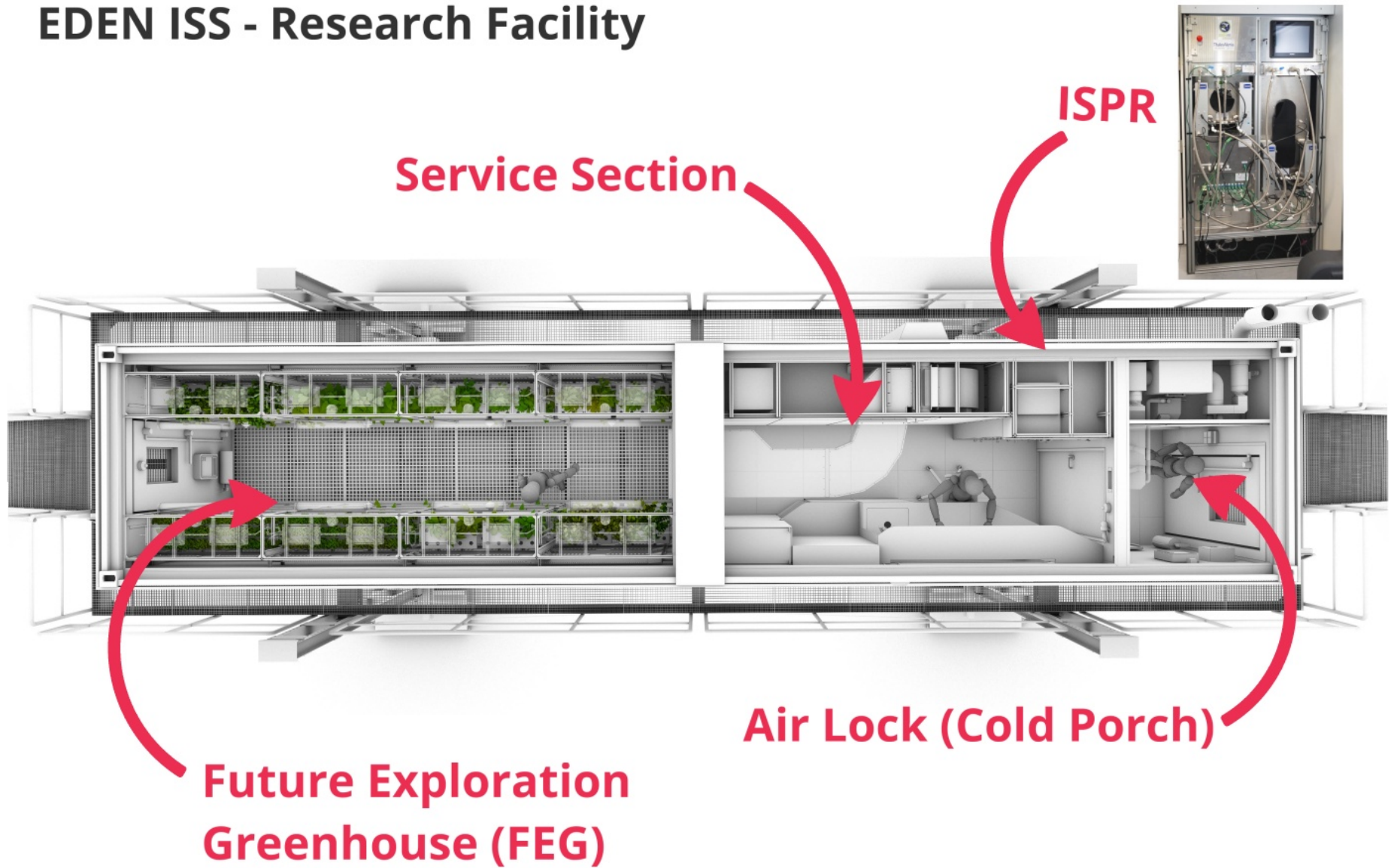


Air Lock (Cold Porch)

EDEN ISS - Research Facility

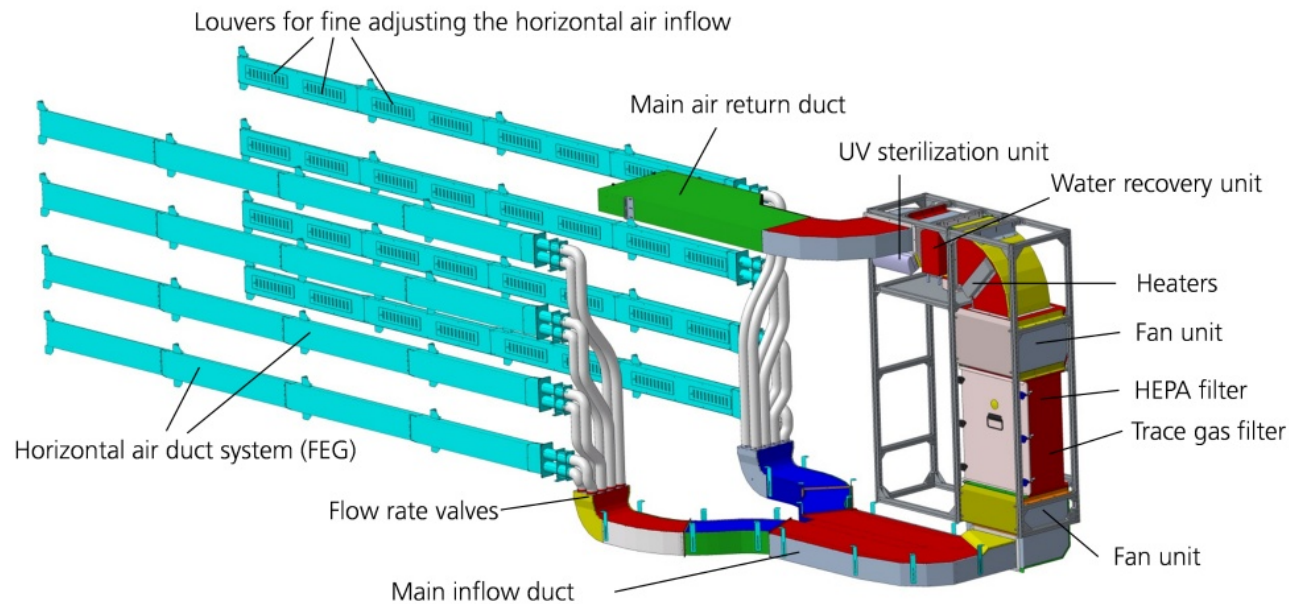


EDEN ISS - Research Facility



Controlled **E**nvironment **A**griculture **(CEA)**

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):



- Exact control of nutrients
- Soiless cultivation (Aeroponics)
- Recirculation => no water loss

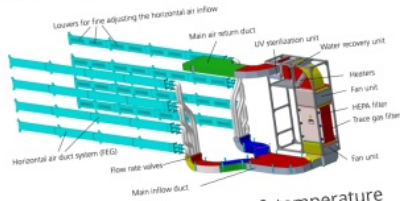
Illumination System (ILS):



- Extended day durations (18/6)
- Exact control of light composition (r/b/fr/w)

Controlled Environment Agriculture:

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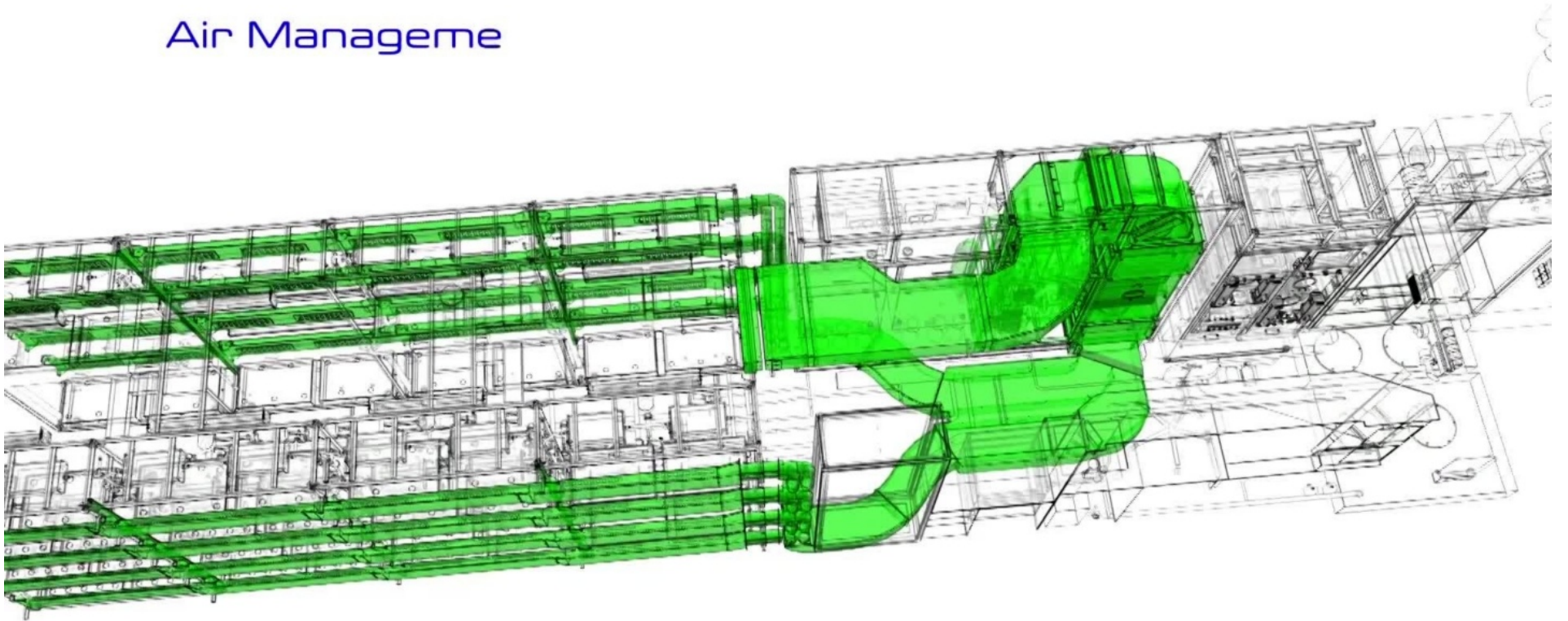
Illumination System (ILS):



- Extended day durations (18/6)
- Exact control of light composition (r/b/fr/w)

- **Artificial cultivation** independent from outside environment
- **Faster** production & **higher yields** than in nature
- **Exact control** of phenotype, taste and useful substances
- **Closed-loop** principle

Air Manageme



Assembly, Integration & Test (AIT)

Construction of the EDEN ISS Greenhouse:



Containers during Spring 2016



Internal sub floor structure of the FEG

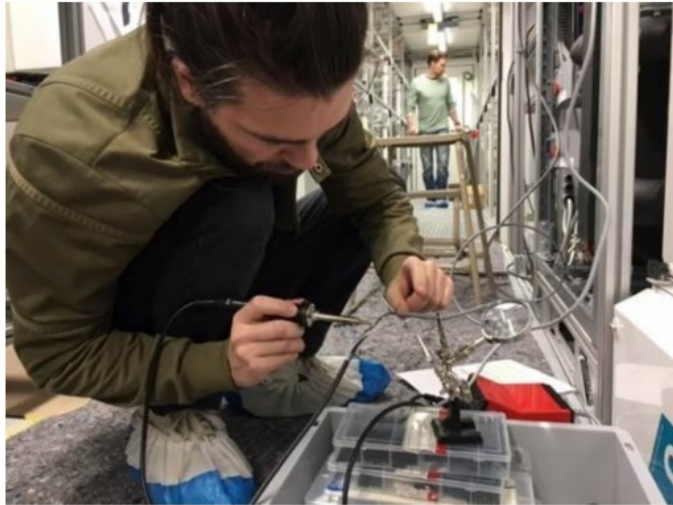


Water tanks



Containers after painting

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

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

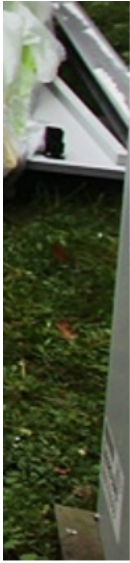


Cleaning the FEG



Final storage of spares & equipment inside the support container





Container in Hamburg harbor



Cleaning the FEG

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

EDEN ISS Integration

- Four weeks of subsystem integration
- Air ducts, NDS and thermal control system piping interface connections
- External hardware installation
- Power & data connection to station



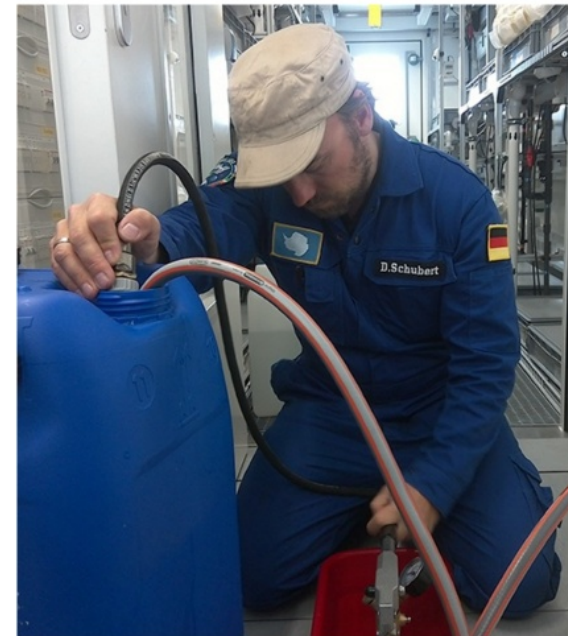
Installing the EDEN ISS containers on the platform (400m away from the station).

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



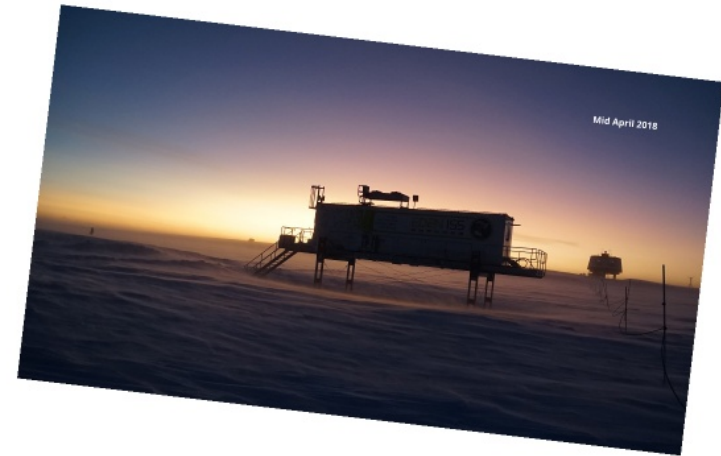
Thermal insulation between the two containers



~Mid February 2018 the EDEN ISS was operational!

Experiment Phase





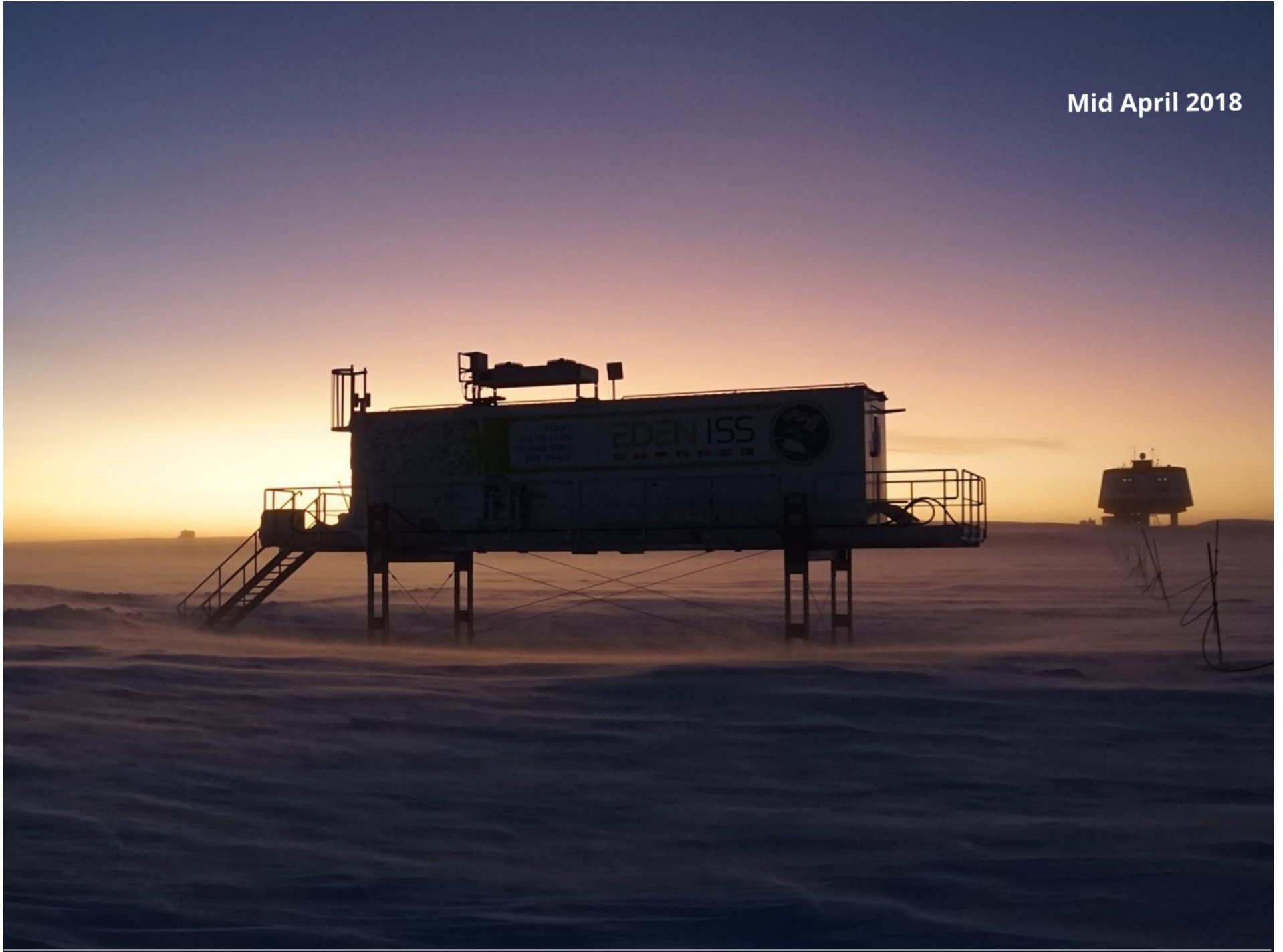
Start of Polar Night



March 2018



Mid April 2018



May 2018



Mid June 2018



Continuous Production



Four lettuce plant trays



Herbs (Chives, Parsley)



FEG during full operation mode



Cucumbers



Four lettuce plant trays

Herbs (Chives, Parsley)



Cucumbers

... after 12 weeks



Fully developed canopy inside the FEG

Just before harvest....



Kohlrabi plant tray



Radish plant tray



Tomatoes plant tray



Swiss chard plant tray



Tomatoes plant tray



Swiss chard plant tray

Edible Biomass



Paul during the first harvest



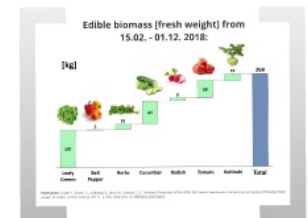
Tomato harvest



Pepper harvest



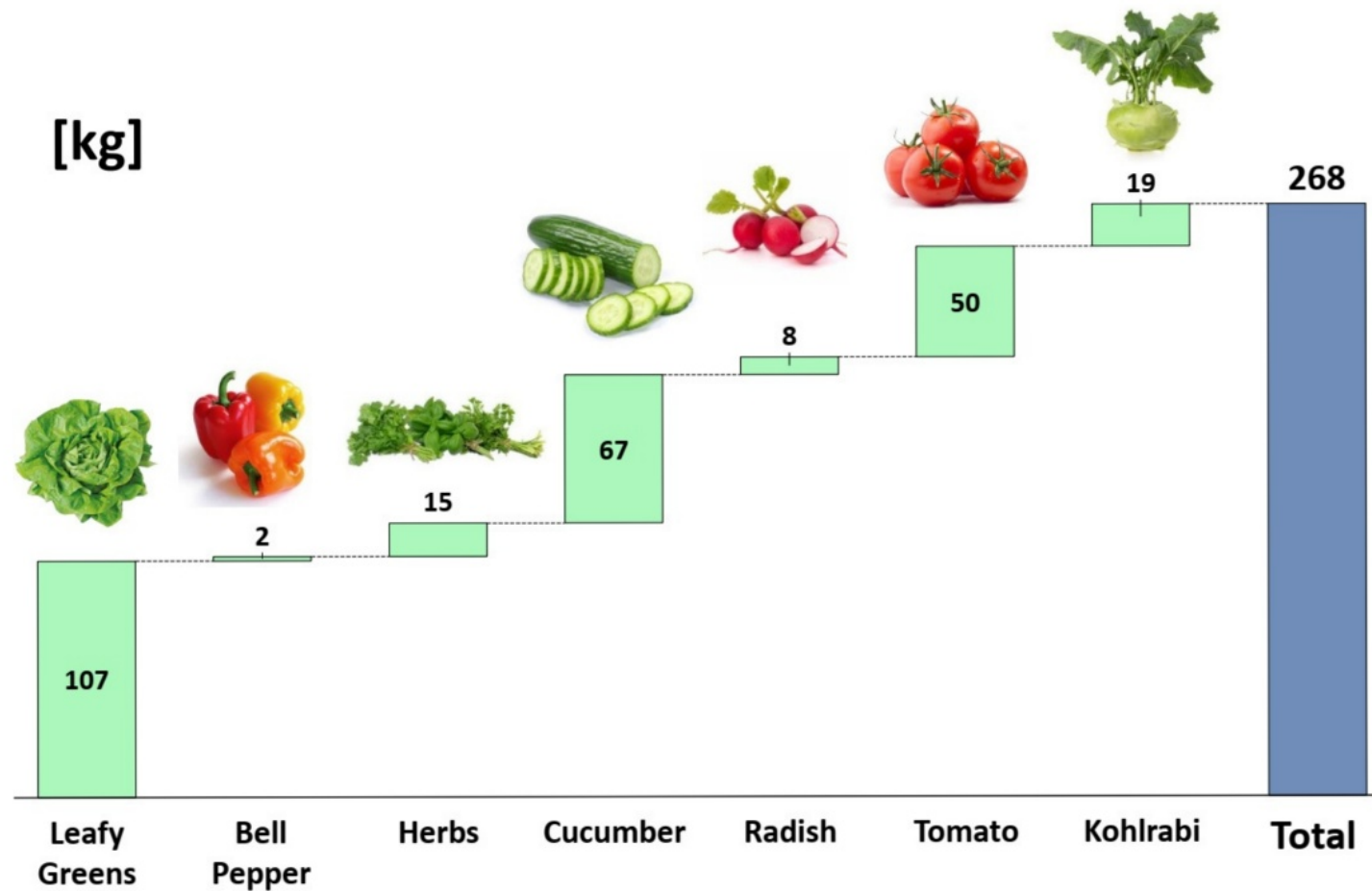
Lettuce harvest





Lettuce harvest

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

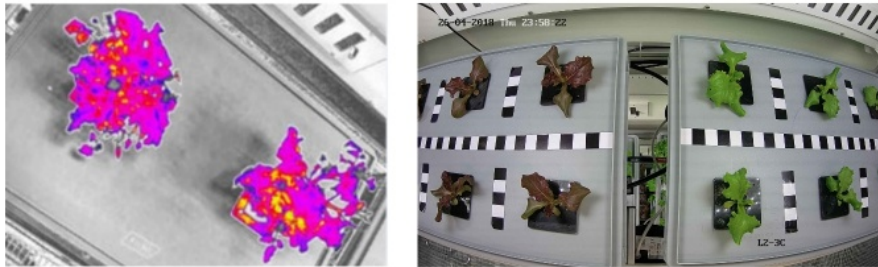


Publication: Zabel, P., Zeidler, C., Vrakking, V., Dorn, M., Schubert, D., "Biomass Production of the EDEN ISS Space Greenhouse in Antarctica during the 2018 experiment phase", *Frontiers in Plant Science*, Vol. 11, p. 656, 2020. DOI: 10.3389/fpls.2020.00656.



Over 40 Experiments & Test campaigns

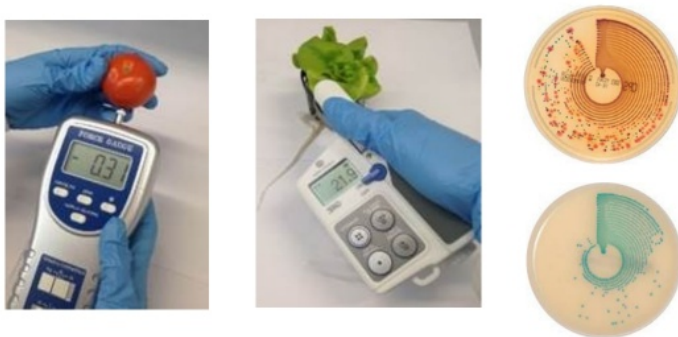
Plant Health Monitoring



Microbial Analysis



Food Quality & Safety



Psychological Investigation



NASA-DLR Mission 2021



NASA-DLR Mission 2021

- Second analogue mission @ NM-III
- NASA scientist (Jess Bunchek) overwintering
- Kennedy Space Center: Plant cultivation group
- Jess is a VEGGIE cultivation system specialist



Jess Bunchek working on the VEGGIE plant cultivation system at NASA



Jess Bunchek (NASA)



NASA-DLR Mission 2021

- Joint science program with ~ 10 different experiments
- Test of dedicated plant cultivation system, based on VEGGIE system



Jess Bunchek (NASA) during post harvest analysis inside EDEN ISS





NASA-DLR Mission 2021



NASA-DLR Mission 2021



Outlook



Development Pathway for Moon



Laboratory Testing

- CEA breadboards
- Functional principles



Analogue Testing

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



Development Pathway for Moon



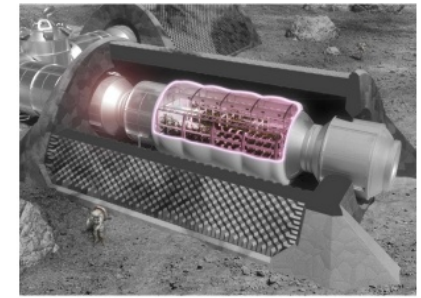
Laboratory Testing

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Space Deployment

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



Development Pathway for Moon



Laboratory Testing

- CEA breadboards
- Functional principles



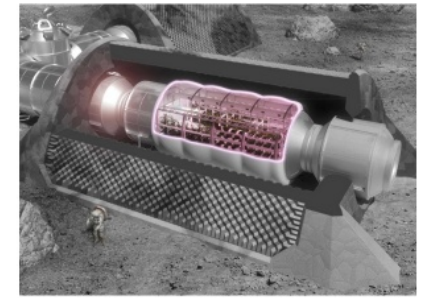
Analogue Testing

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Ground Testbed

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



Space Deployment

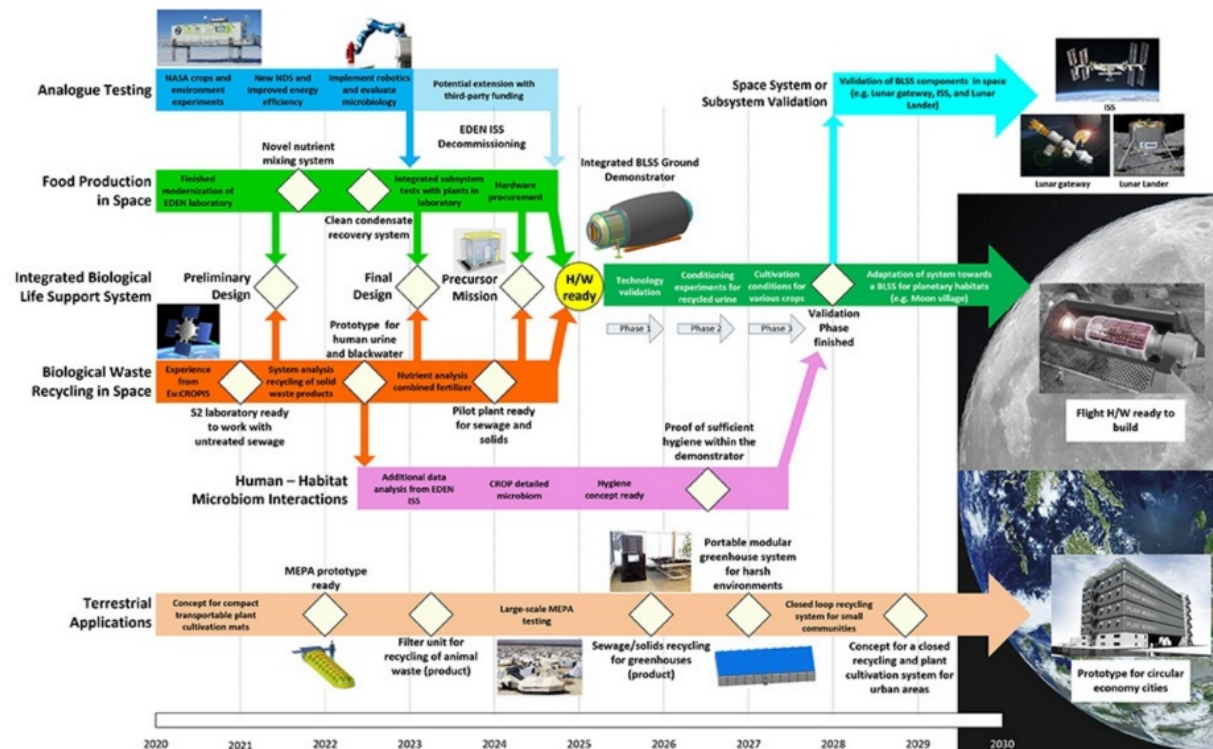
- Full space flight system
- Bio-regenerative Life Support System



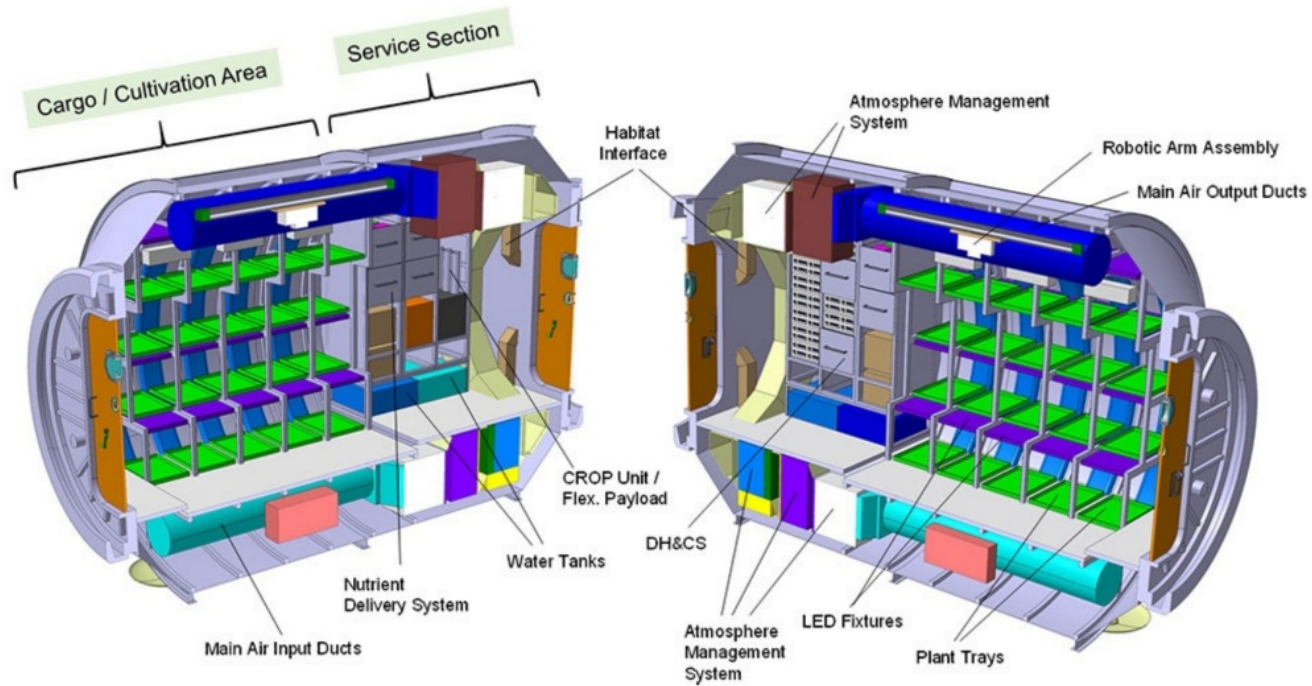
DLR Roadmap 2020 - 2030

R&D Roadmap for Bio-regenerative Life Support Systems (BLSS)

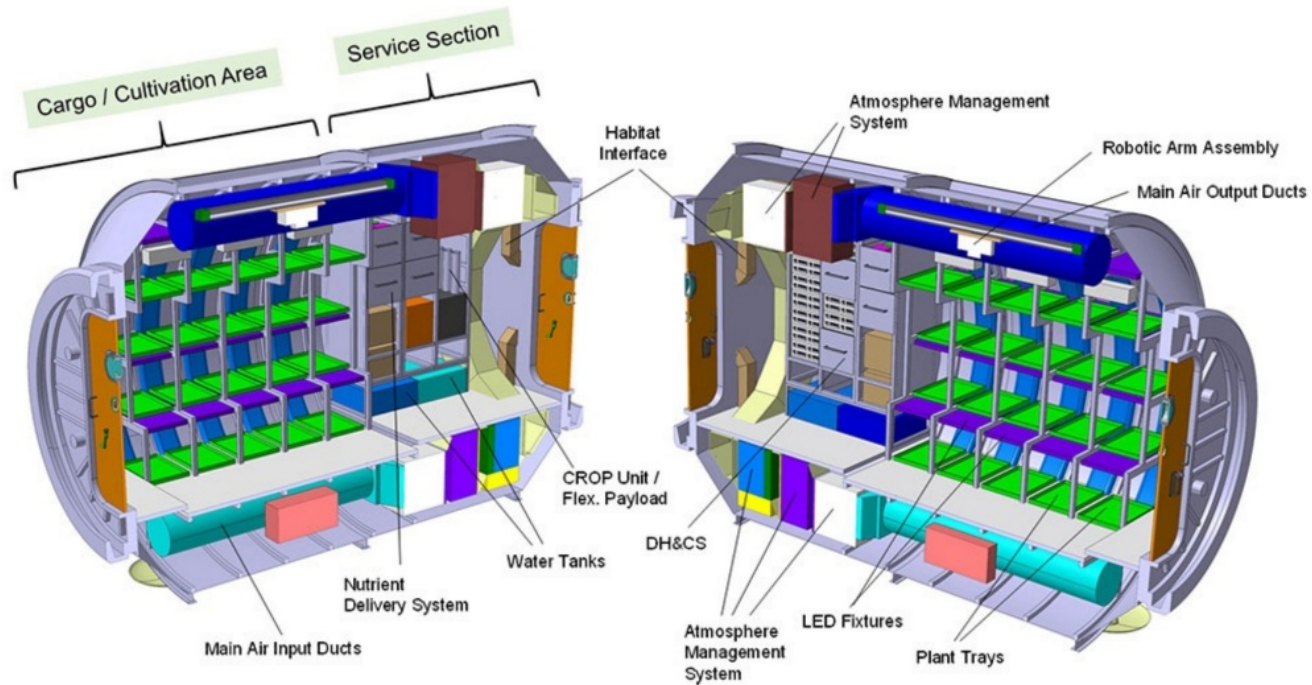
Goal: Development of **space-ready design** of lunar greenhouse by (~)2025



Logistic-to-Life Support

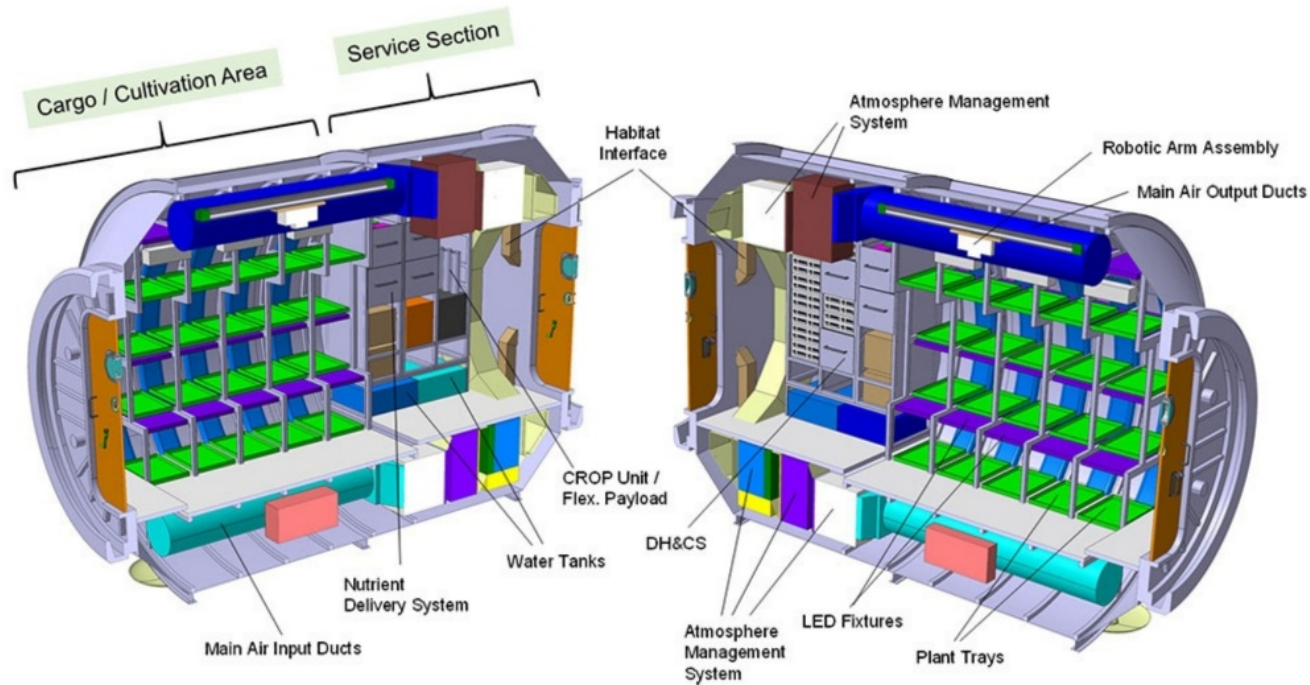


Logistic-to-Life Support



First cargo module...

Logistic-to-Life Support

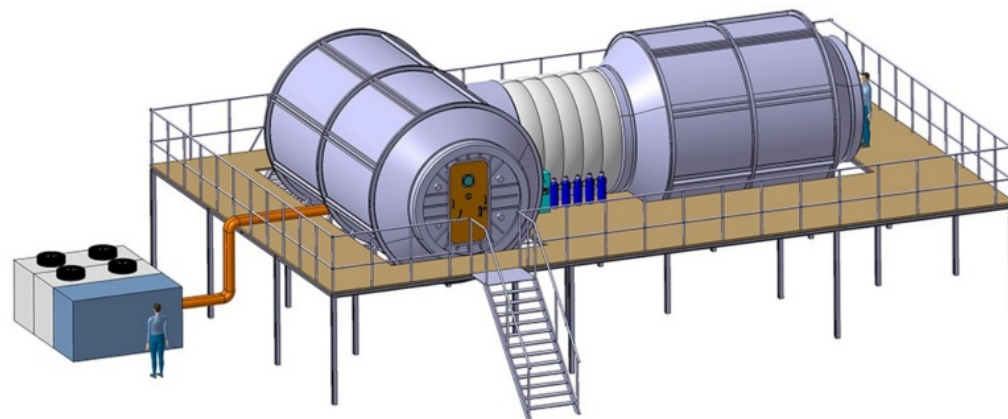


First cargo module...

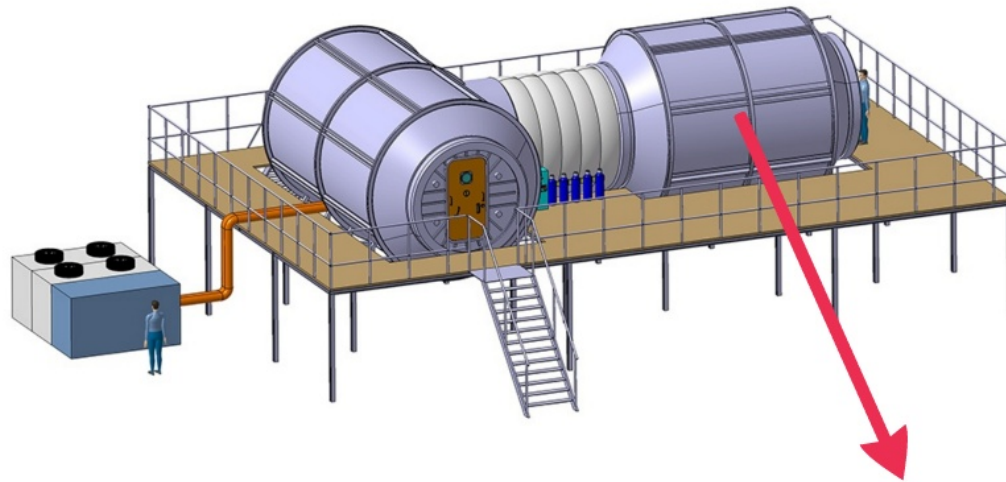


... then greenhouse module!

Ground Test Demonstrator



Ground Test Demonstrator

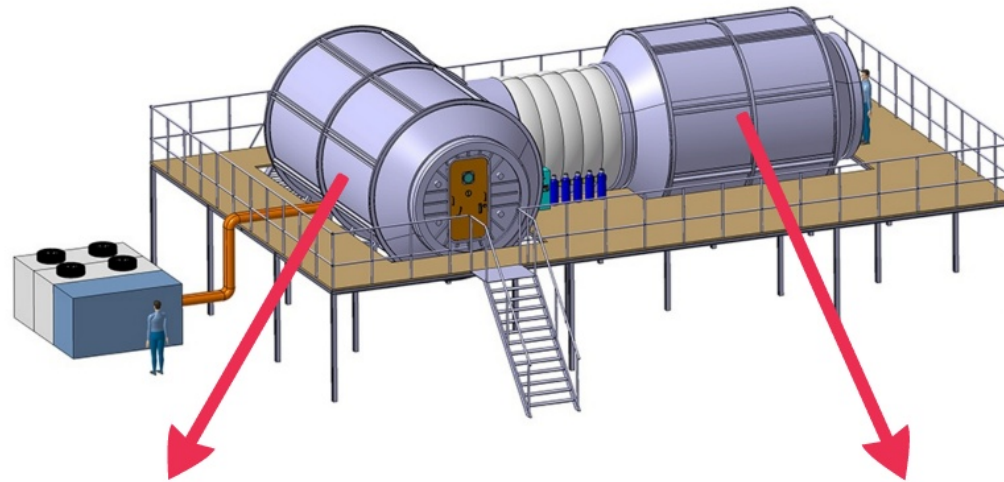


Greenhouse Module:

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



Ground Test Demonstrator



Habitat Simulator:

- Integrated laboratory (Sample & consumables storage)
- Food Processing Facility => ("Space Kitchen")
- Additional food systems (e.g. artificial meat)
- Food storage technologies



Extended food storability



Space Kitchen



Other food technologies

Greenhouse Module:

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



International Collaboration



- Official Lol signature of CSA at IAC in Paris 2022
- Long-term partnership within DLR's roadmap
- Subsystem contribution by CSA



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).



Technology Transfer

Designed for space ... used on Earth!

**Vertical Farming applications
=> Mega trend**



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

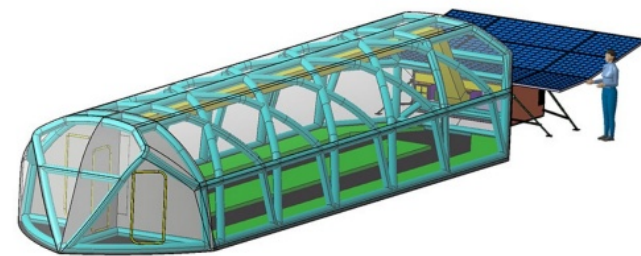


(Source: Innovatus Inc., Japan, 2016)

**Fast & independent food
production**



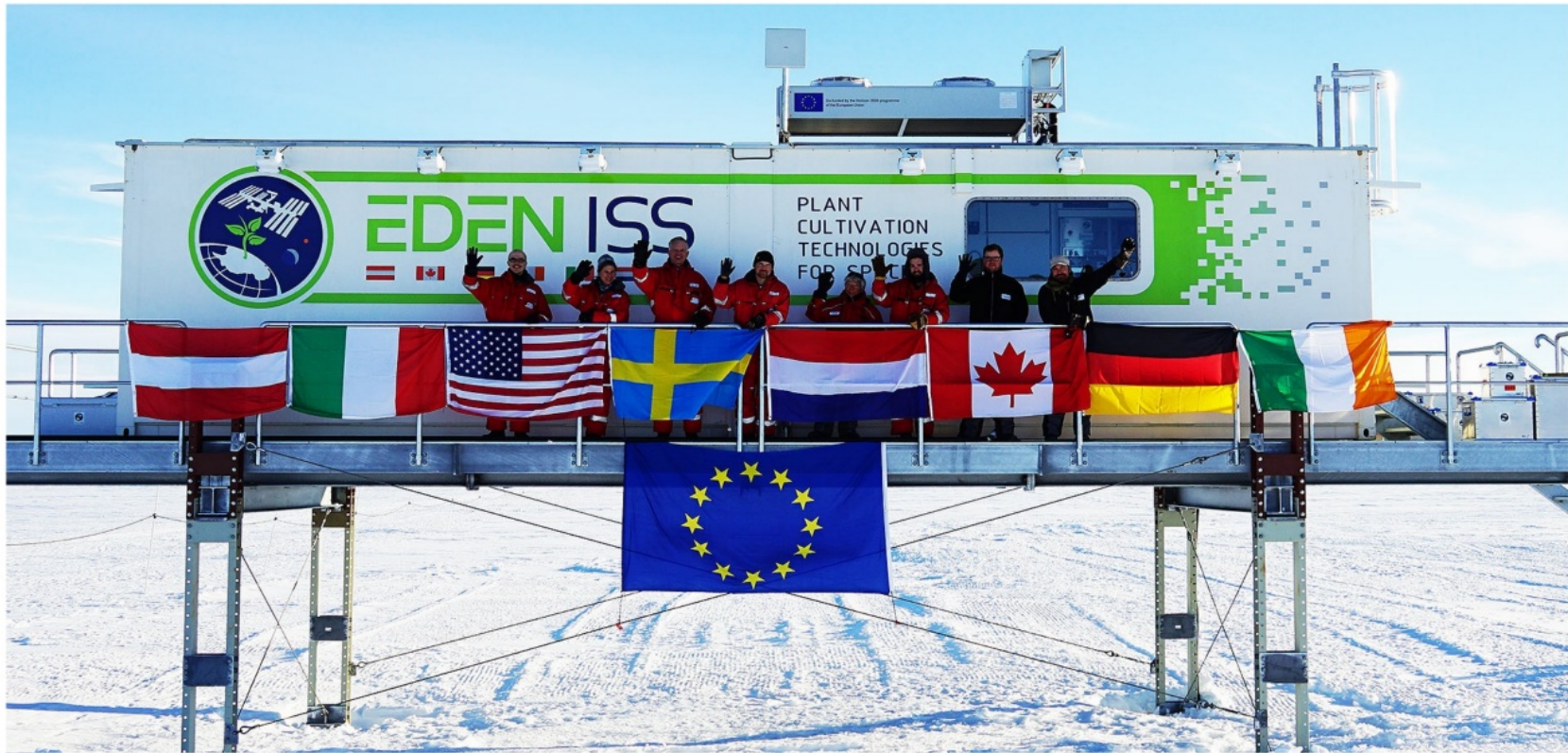
Refugee camp in Jordan (Source: UNO)



HumTech Project at DLR (MEPA)

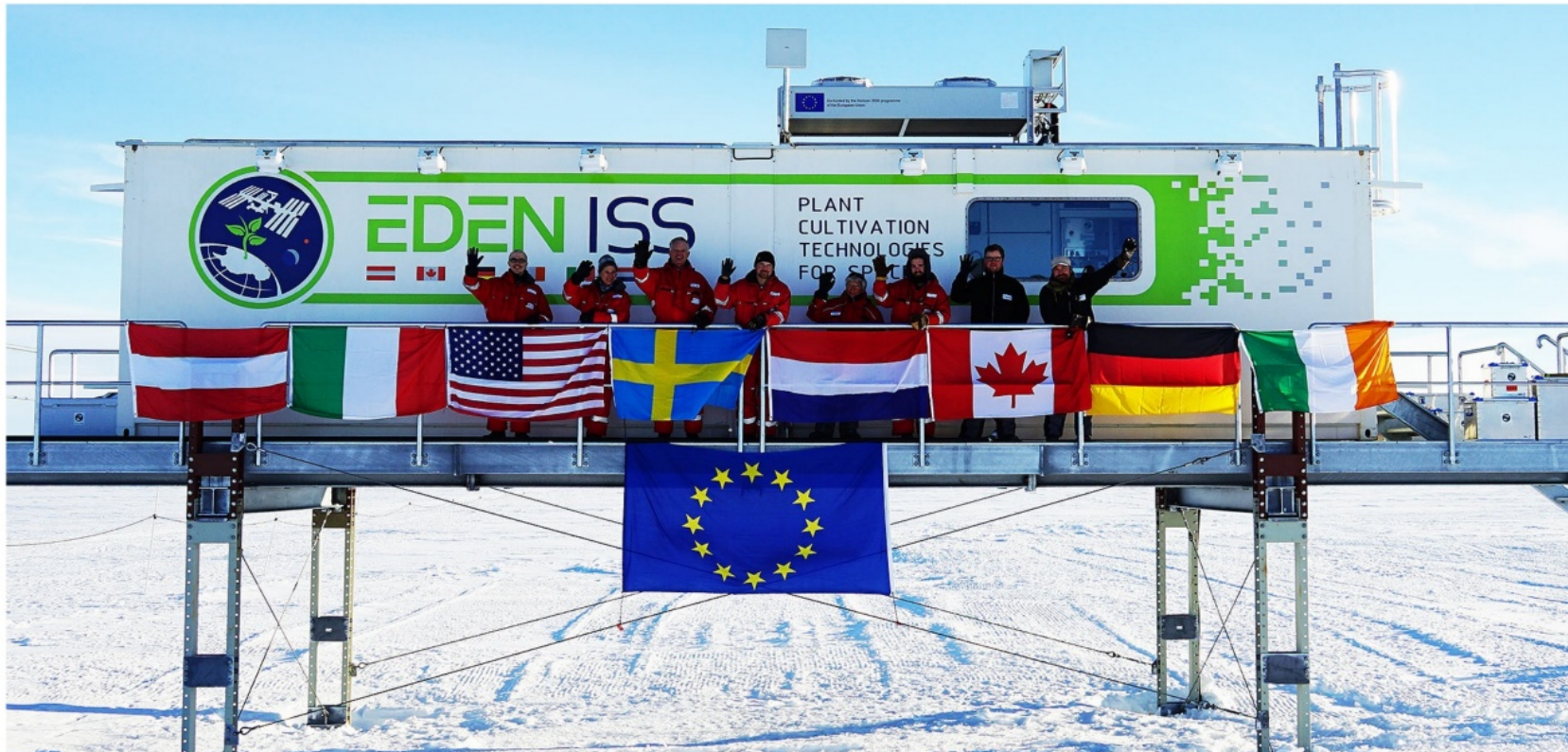
Summary

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- EDEN ISS: Plant cultivation technologies for space



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- Several years of analogue testing @ NM-III (Antarctica)



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- Future plan: Integrated life support module (DLR Roadmap)



Summary

- EDEN ISS: Plant cultivation technologies for space
- Several years of analogue testing @ NM-III (Antarctica)
- Joint NASA-DLR science mission in 2021
- Future plan: Integrated life support module (DLR Roadmap)
- Huge potential for terrestrial spin-off applications (e.g. Vertical Farming)



Thank you for your Attention!



www.eden-iss.net

