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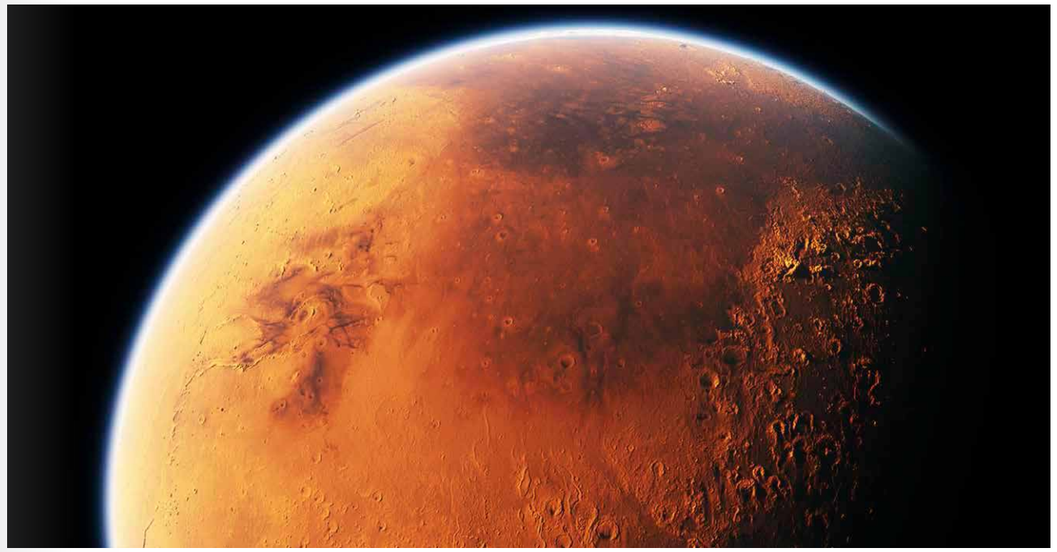
HIGHLIGHTS 2016

YEARLY STATUS REPORT
EDEN INITIATIVE

DLR



Mars - a target for future human exploration

EDEN – THE YEAR 2016

SpaceX founder Elon Musk outlines his plans for a human presence on Mars, ESA pushes its ambitions for an international Moon village, and DLR establishes the Orbital Hub concept as a possible ISS successor. In this sense, 2016 marked an outstanding year for human spaceflight.
The EDEN team contributed to these ambitions with technical solutions and paved the way on the political agenda in the same motivated manner like the years before.
The EDEN ISS project gained speed and the successful development of various systems was accomplished. The Critical Design Review marked an important milestone, and in September, the Mobile Test Facility was delivered to DLR for the Assembly, Integration, and Test phase.
Paul Zabel, who will live for one year in Antarctica, received basic training on hydroponic plant cultivation and treatment at our EDEN ISS partner University of Wageningen (NL). This way the EDEN team is prepared for the space analogue mission to Antarctica in 2018.
Another highlight was the continued progress within the DLR internal project C.R.O.P, where tomatoes were successfully tested in the lab's clean room with the dedicated urine-based nutrient solution. This joint research project between DLR-RY and DLR-ME will further push the boundaries of Bio-regenerative Life Support Systems.
Establishing a clear political agenda and pushing for more international collaboration is essential in the space sector and is actively pursued by the EDEN team. Here, the White Paper could officially be published, after two years of coordination under the lead of the EDEN group.
This unique position paper outlines the strategic roadmap of the space agriculture community.
Like two years ago, the EDEN team assisted in the organization of the AGROSPACE event together with AeroSekur and the University of Arizona. Preceding the conference the team organized the European-Chinese Collaboration Workshop on Closed-loop Technologies for Space, Antarctica and Urban Areas. Leading experts from China, Germany and European industry participated in several collaboration events, held in Bremen and Sperlonga.
2016 was a very successful year with increasing publications, further won projects for system developments and outreach purposes. The EDEN team is confident to continue this pathway into 2017 in order to foster humanity's plan for space exploration and to establish a human presence in our solar system beyond Earth.

Daniel Schubert

Inside of an EDEN Lab aeroponic plant growth tray

EDEN Lab grown peppers

THE EDEN INITIATIVE

In 2011, the DLR Institute of Space Systems launched its research initiative called EDEN: Evolution & Design of Environmentally-closed Nutrition-Sources. The research initiative focuses on Bio-regenerative Life Support Systems (BLSS), especially greenhouse modules, and how these technologies can be integrated in future space habitats.
EDEN was established within the DLR internal project C.R.O.P (Combined Regenerative Organic-Food Production) – a joint research endeavor between the Institute of Aerospace Medicine (ME) and the Institute of Space Systems (RY).
It is the goal of the EDEN team to further advance the latest cultivation technologies and to adjust these developments into space related applications. Even though present scenarios for future human missions to Moon and Mars are still several years from coming to fruition, the time to develop these technologies needs to start today. Only this way, highly-reliable and resource-efficient BLSS will be ready for implementation into the mission architecture for humanity's journey to the Moon and Mars.
The EDEN Initiative is administered by the Department of System Analysis Space Segment (SARA) at DLR Bremen. The department operates the institutes Concurrent Engineering Facility (CEF) as well as the Space Habitation Plant Laboratory (EDEN Lab). Furthermore, the EDEN group receives support from the institute's Electronic Laboratory (E-Lab), and utilizes the institute's laboratory building (incl. integration hall) in order to foster the development of cutting-edge plant cultivation technologies.

DLR Institute of Space Systems, Bremen (Germany)

Matthew Bamsey making up hydroponic nutrient solution within the EDEN Lab analytical room

THE EDEN TEAM

DANIEL SCHUBERT studied at the Technical University of Berlin and has an engineering diploma in industrial engineering with emphasis on aerospace and production techniques. In 2011, he initiated the EDEN group at the DLR Institute of Space Systems for technology investigations on Bio-regenerative Life Support Systems and is since then the team leader of this group. His research expertise is set on habitat interface analysis and plant accommodation and dynamic plant production planning.

CONRAD ZEIDLER is member of the EDEN research team since January 2011. Within his Industrial engineering diploma at the Technical University of Braunschweig he specialized on aerospace engineering and has profound knowledge trade-off analysis techniques (e.g. AHP).
He is an expert in simulation methods and control software. Within EDEN, he is responsible for monitoring and controlling the plant growth and environment parameters.

Dr. MATTHEW BAMSEY holds a M.Sc. in aerospace engineering (University of Colorado, USA) and conducted his Ph.D. in environmental biology with the University of Guelph (Canada). Matthew worked as a postdoctoral researcher at the University of Florida where he supported suborbital plant growth payload developments. He spent over ten years working as an intern at the Canadian Space Agency where he worked with the Arthur Clarke Mars Greenhouse project. Within EDEN, he conducts research related to nutrient delivery systems.

PAUL ZABEL studied aerospace engineering at the Technical University of Dresden. He joined the EDEN team in 2012. Mr. Zabel is the deputy manager of the EDEN Lab and is working on acquiring funding and projects for EDEN. His research expertise is hybrid Life Support Systems containing greenhouse modules and physical/chemical LSS. Funded over NPI (ESA) he is doing his Ph.D. about the dynamic behavior of such hybrid systems.

Chen Dong holds a M.Sc. in genetic breeding (Nanjing Forestry University, China) and is doing his Ph.D. in biological engineering with Beihang University (Beijing, China). During his Ph.D. research, Chen was selected from several candidates to participate in the Chinese Lunar Palace-1 Mission for 105 days in 2014. He lived together with two other crew members in a space simulation bio-regenerative life support system facility in Beijing. Chen is presently working with the EDEN team as a guest scientist under a scholarship from the China Scholarship Council.

VINCENT VRAKKING studied at the Technical University of Delft in the Netherlands and holds a M.Sc. in aerospace engineering. He has worked with the EDEN team on and off since 2012, before joining the team in 2015. Within the EDEN group he investigates the potential use of lightweight inflatable materials and structures that can house Bio-regenerative Life Support Systems and greenhouse systems in particular.

EDEN ISS – CRITICAL DESIGN REVIEW

DESIGN TEAM MEETS REVIEW BOARD

On March 17th and 18th the EDEN ISS partners, the project's Scientific Advisory Board (SAB), and the project coordinator of the European Union met at DLR's Institute of Space Systems in Bremen for the Critical Design Review (CDR).
As project lead, the EDEN team handled the logistics and organizational aspects necessary for the meeting (~60 scientists & engineers), as well as the tasks associated with collecting, writing and reviewing the subsystem design documentation.
The CDR consisted of a review and discussion of each subsystem design and addressed the concerns raised by the SAB. Over the course of the two day CDR, the consortium managed to address the majority of the issues which had been raised, reducing the number of Review Item Descriptions (RIDs) from initially 152 to 18 at the end. The remaining RIDs were subsequently closed through follow up actions from the consortium partners.
Two months later, in May, the EDEN team presented the design of the EDEN ISS facility to independent reviewers, selected by the project coordinator of the European Research Executive Agency (REA), in Brussels. The review was very positive, with only minor comments for possible improvements.

Discussions during the EDEN ISS CDR

Participants of the EDEN ISS CDR

Giuseppe Bonzano (AS), Marco Volponi (TASI), Antonio Cerielle (TPZ), Giorgio Boscheri (TASI) and Anthony Gilley (HS) working in between CDR sessions

Four of the six members of the EDEN ISS Scientific Advisory Board (Prof. Yoshiaki Kitaya, Prof. Gene Giacomelli, Prof. Stefania De Pascale, Dr. Raymond Wheeler)

Christos Ampatzis (REA) and Daniel Schubert in discussion

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 636501

Plants growing in a 3D printed aeroponics tray

EDEN ISS aeroponic tomatoes growing under a Heliospectra LED panel

Visiting scientist Chen Dong checking in on plants growing in the ORBITEC Biomass Production System for Education

Post-harvest measurements of EDEN Lab grown cucumbers

EDEN LAB

PLANT GROWTH TESTS FOR ANTARCTICA AND SPACE

In 2016, the experiments in the EDEN laboratory continued and major system improvements could be accomplished and essential knowledge was gathered. Several growth cycles with the tall growing EDEN ISS crop candidates were conducted (e.g. cucumber). Here the EDEN team tested different grow arrangements. Different varieties of bushy tomatoes were tested to come closer to a final decision on the cultivar selection for the EDEN ISS Antarctic mission. Furthermore, small sweet pepper plants were cultivated for two growth cycles to study their grow behavior. The collaboration with OSRAM on the high-performance, water-cooled LED system developments was strengthened and the dedicated growth chamber was upgraded with new versions of these prototype LED lamps. A test growth cycle confirmed that the lamps are working properly.
Besides the experiments with LED lamps and EDEN ISS cultivars, the DLR Combined Regenerative Organic Food Production (C.R.O.P.) project continued with experiments on the urine-based nutrient solution. In early 2016, fruits of the first MicroTina (tomatoes) cultivation experiments were successfully harvested and two more growth cycles followed with different nutrient solution setups.

MicroTina growth experiment using C.R.O.P solution

EDEN Lab online nutrient delivery system after several 2016 modifications

Pierre Delmotte aiding in post-harvest measurements

Ralf Gente (University of Marburg) conducting an investigation of water status in aeroponically irrigated plants using new measurement techinques within the EDEN Lab

MicroTina following laboratory harvest

EDEN Lab grown cucumbers

EDEN Lab grown lettuce

HIGHLIGHTS 2016

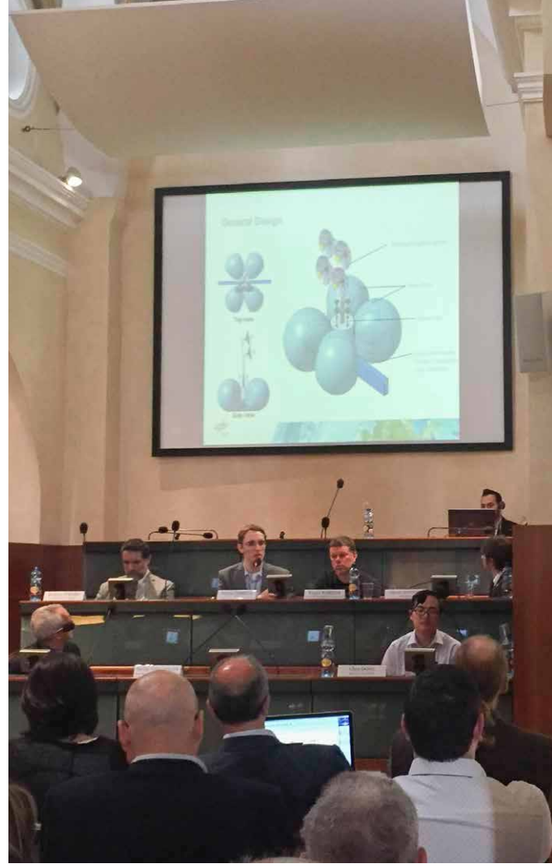
Interior view of an EDEN Lab growth chamber incorporating a 1 m x 1 m aeroponic growth tray

Sperlonga - the bi-annual home of the AGROSPACE workshop

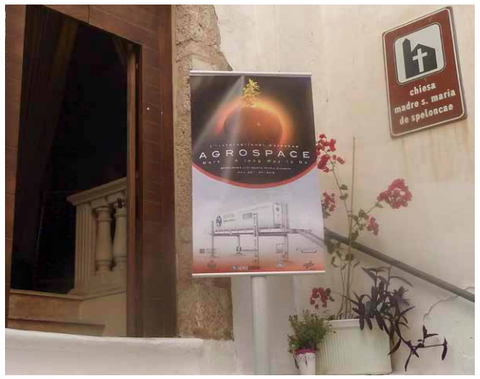
AGROSPACE 2016

MARS – A LONG WAY TO GO

'Mars – A Long Way to Go' was the title of the 7th International AGROSPACE conference held in the beautiful Santa Maria Church of Sperlonga (Italy) from the 26th and 27th of May 2016. The conference was organized by Aero-Sekur with the collaboration of the EDEN team and University of Arizona. The international space agriculture community gathered together in order to exchange knowledge on the latest developments of closed-loop agriculture in space. Like two years ago, the EDEN team actively participated in the organization of the conference starting from the selection of the scientific presentations, outfitting the conference bags, organizing the poster sessions as well as hosting social events.
Furthermore, the conference marked the official date for announcement of the White Paper, which is a positioning paper, initiated by the EDEN group at the AGROSPACE 2014. The paper outlines the different areas of plant cultivation in space, its benefits, and its potential for terrestrial markets. The EDEN group coordinated the two year-long harmonization process among the supporters. The White Paper has 24 signatories from academia, research organizations and industry. A copy of the White Paper can be found at the end of this report.



Vincent Vrakking presenting the results of the ESA MELiSSA greenhouse module design study



The well decorated entry into the AGROSPACE venue, the former Santa Maria Church

Pre-workshop preparation of conference materials by AeroSekur and DLR staff members

AeroSekur plant growth units on display at AGROSPACE 2016

Wageningen University and Research lettuce harvest under different treatments

WAGENINGEN TRAINING

ANTARCTIC GROWERS WANTED!

In May, Paul spent a week at the Wageningen University and Research, one of the EDEN ISS project partners. He received this dedicated training by horticulture experts as preparation for his one year mission in Antarctica. The week was strictly planned with hands-on work in the greenhouse facilities and meetings with several scientists. In two dedicated EDEN ISS climate chambers, Esther Meinen and Tom Dueck were cultivating the selected plants that are considered for the expedition to Antarctica. These include many varieties of lettuce, spinach, herbs, as well as cucumbers, tomatoes, peppers, and strawberries. Paul was trained on harvesting procedures, how to characterize plant morphology, and how to prune plants to help them grow as required. Furthermore, he learned techniques on early pest detection and plant disease control. Early August, Paul went back to Wageningen for another training session. Again he assisted in working with the plants in the EDEN ISS climate chambers. During his stay, he gained basic knowledge on plant nutrition and nutrient solutions. This way Paul obtained a great deal of valuable knowledge, essential for the upcoming analogue mission in Antarctica.

Paul Zabel during training in Bleiswijk (NL)

View of a section of one of the two Wageningen growth chambers dedicated to EDEN ISS

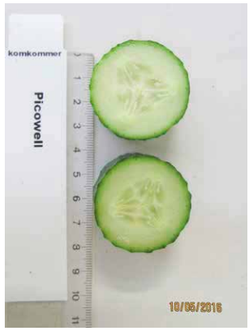
EDEN ISS plant growth trials

Paul Zabel conducting post-harvest measurements in Wageningen

EDEN ISS grown radish

A showing off of Wageningen EDEN ISS growth trial harvested plants

Tom Dueck (WUR), Willem de Visser (WUR) and Esther Meinen (WUR) discussing the on-going EDEN ISS experiments



Post-harvest cucumber measurements

HIGHLIGHTS 2016

Ruby Red Swiss chard grown under different EDEN ISS light treatments

A day we were all looking forward to. Oct 7, 2016 the day the EDEN ISS containers arrived at DLR

EDEN ISS – STATUS

ASSEMBLY, INTEGRATION, AND TEST

2016 was very much the year where the design of the Mobile Test Facility (MTF) went from being an on paper design to a manufactured system. The EDEN ISS subsystem leads did an amazing job in advancing their designs and subsequently developing their hardware. The critical design review was a key milestone of 2016 as was a subsequent review of the project in Brussels by the European Research Executive Agency (REA). The EDEN ISS project also received project approval from the German Environment Ministry (Umweltbundesamt), permitting the shipment of the first EDEN ISS project related hardware to Antarctica, such as the completed elevated platform, power cable and CO2 bottles.
Activities continued to ramp up until the commencement of the assembly, integration and test (AIT) phase of the MTF. Finally, on October 7th, the two MTF containers were delivered to DLR Bremen and installed behind the main office building. The AIT tent in conjunction with the newly acquired K.10 laboratory in the basement of the institute form the backbone of the work space required for final subsystem testing and integration activities. The power system was the first subsystem integrated into the MTF with wiring commencing immediately following container delivery. The control and data handling system (Argus system) and the nutrient delivery system came next. The air management system, thermal system and illumination system were also delivered and partly installed before the December holidays.

Early view of the Future Exploration Greenhouse subfloor area

Construction of the AIT tent platform

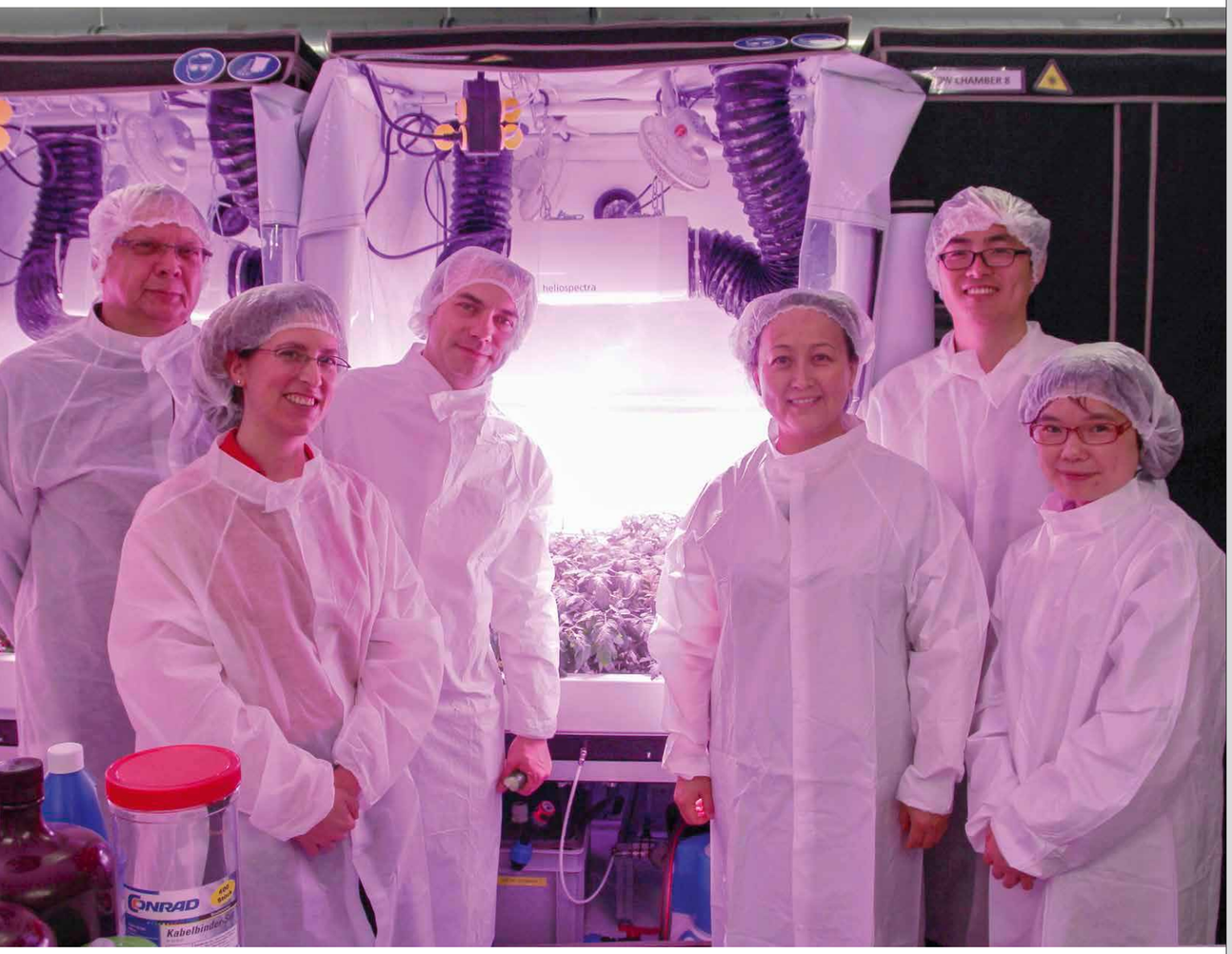
The EDEN ISS containers being offloaded by crane during delivery to DLR Bremen

A view of the newly delivered MTF with its adjacent AIT tent

Illustrative impression of the EDEN ISS Mobile Test Facility (Image credit: LIQUIFER Systems Group)

Daniel Schubert giving introductory remarks to kick off the workshop

Discussions during an institute tour



Dr. Klaus Slenzka (OHB System AG), Sandra Podhajsky (OHB System AG), Daniel Schubert, Prof. Hong Liu, Chen Dong, Prof. Beizhen Xie during a tour of the EDEN Lab

Participants of the European-Chinese Collaboration Workhop in the main DLR meeting room

EUROPEAN-CHINESE COLLABORATION WORKSHOP

PREPARING THE PATHWAY FOR COLLABORATION

In May, the EDEN team organized the 'European-Chinese Collaboration Workshop (ECCW) on Closed-loop Technologies for Space, Antarctica and Urban Areas'. The workshop was co-financed by the DLR department for Strategy and International Relations (VO-ST) and aimed at facilitating future collaborative efforts between the EDEN group and China's leading experts on bio-regenerative closed-loop technologies. Contacts were established between delegates from Beihang University, OHB Bremen, as well as international partners of the EDEN group. The Chinese Beihang University is the operator of the closed-loop test facility, called Lunar Palace One.

The workshop consisted of two days in Bremen, during which the Chinese delegation toured DLR and OHB facilities and participated in discussions about possible areas of collaboration, followed by three days at the AGRO-SPACE conference (Italy).

Despite certain regulatory and budgetary concerns currently restricting joint research efforts with Chinese partners, the EDEN group and Beihang University identified several areas of common interests and are committed to further exploring and developing avenues for mutually beneficial partnership.

Chen Dong of the Beihang University was guest scientist within the EDEN group for one year. He successfully conducted several growth trials within the EDEN Lab and supported the team in all aspects. His exchange year ended in September and the EDEN Team wishes him all the best for his upcoming research in China!

Chen Dong, Prof. Hong Liu and Dr. Beizhen in the EDEN Lab

Prof. Hong Liu describing the 105 day Lunar Palace experiment

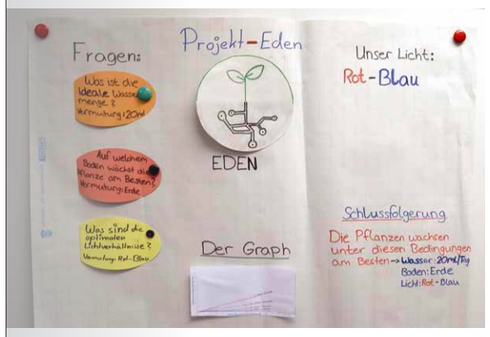
EDEN FOR KIDS

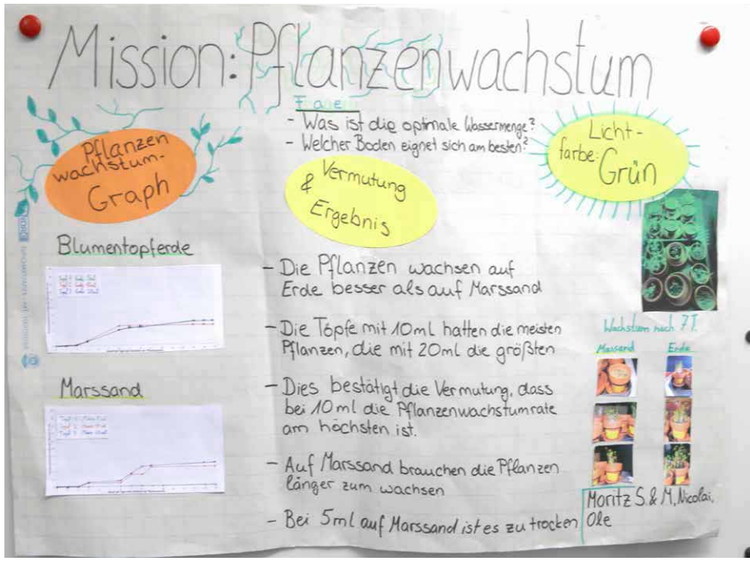
EDUCATION FOR A SUSTAINABLE FUTURE

Do plants grow on Martian regolith? Which light spectrum do plants need to grow? Which environmental factors are optimal for extraterrestrial greenhouses on the Moon or Mars? These and other research questions were investigated by several students of the 7th and 8th grades in 2016 in the DLR_School_Lab in Bremen. The pupils conducted different growth experiments in their classroom, using dedicated EDEN growth chambers with adjustable LED lights and an air management system for temperature and humidity control.
With the EDEN for Kids project, the DLR_School_Lab in close collaboration with the EDEN team and the department of biology didactics of the University of Bremen continues its educational outreach program.
Since October, the EDEN for Kids project is financial supported by the Robert Bosch Stiftung in the context of the "Our Common Future" program. The funding allows the team to upgrade the outreach equipment by purchasing professional grow chambers. During the school campaigns, the pupils from different schools will not only exchange their results and experiences, but also visit the EDEN lab and meet the EDEN scientist. This learning program will be continued and steadily improved within the coming years in order to enhance the awareness for space exploration and sustainability on Earth.

The new EDEN outreach tool: The PlantCube from Agrilution. In 2017, school classes will conduct plant cultivation experiments with this new multi-level growth chamber

Hannah Effertz (School_Lab) introducing the plant growth chambers to a school class





Poster, created by the school class research teams, in order to present their results

Final presentation day at the School_Lab (Bremen), discussing the EDEN research results, made by the pupils

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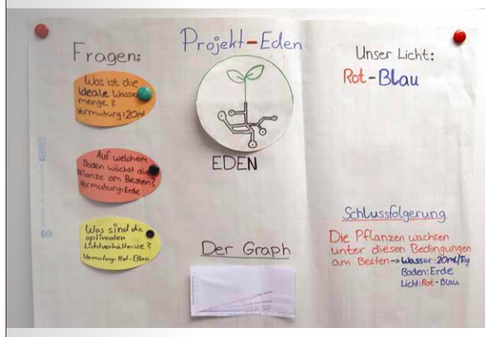

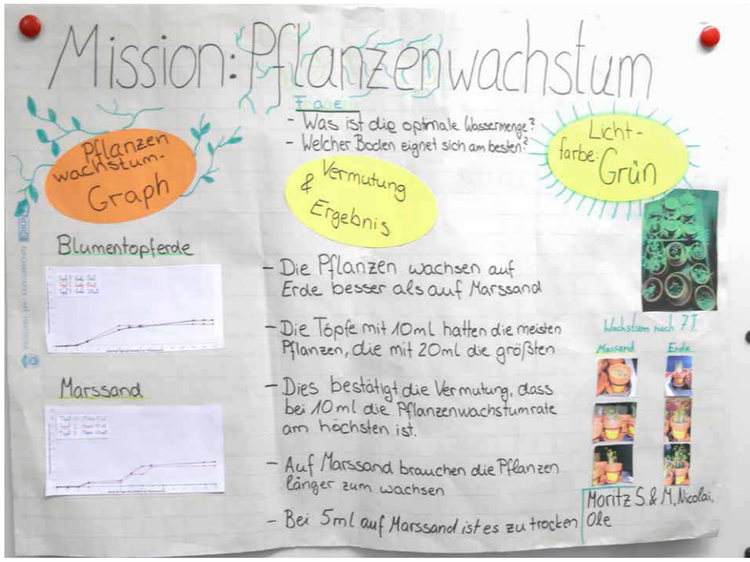

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Final presentation day at the School_Lab (Bremen), discussing the EDEN research results, made by the pupils

KEY FIGURES - 2016

JOURNALS

M. Mauerer, D. Schubert, P. Zabel, M.T. Bamsey, E. Kohlberg: *"Survey on fresh fruit and vegetable preferences of former crew members of a space analogue environment"*, Open Agriculture - Topical Issue: Agriculture in Space, 2016

P. Zabel, M.T. Bamsey, D. Schubert, M. Tajmar, *"Review and analysis of over 40 years of space plant growth systems"*, Life Sciences in Space Research, Vol. 10, pp.1-16. 2016

PEER-REVIEWED CONFERENCE PROCEEDINGS

P. Zabel, et al., *"The preliminary design of the EDEN ISS Mobile Test Facility - An Antarctic greenhouse"*, 46th International Conference on Environmental Systems, Vienna, Austria, 10-14 July, 2016

G. Boscheri, V. Guarnieri, C. Iacopini, I. Locantore, M. Lamantea, C. Lobascio, D. Schubert, *"The EDEN ISS Rack-Like Plant Growth Facility"*, 46th International Conference on Environmental Systems, Vienna, Austria, 10-14 July, 2016

M.T. Bamsey, P. Zabel, C. Zeidler, V. Vrakking, D. Schubert, E. Kohlberg, M. Stasiak, T. Graham, *"Early trade-offs and top-level design drivers for Antarctic greenhouses and plant production facilities"* 46th International Conference on Environmental Systems, ICES-2016-201, 2016

I. L. Schlacht, B. Foing, O.b Bannova, F. Blok, A. Mangeot, K. Nebergall, A. Ono and D. Schubert, *"Existing and new proposals of Space analog, off-grid and sustainable habitats with Space applications"*, 46th International Conference on Environmental Systems, ICES-2016-367, 2016

A. Santos, M.T. Bamsey, V. Infante, D. Schubert, *"A case study in the application of failure analysis techniques to Antarctic Systems: EDEN ISS"*, 2nd IEEE International Symposium on Systems Engineering, Edinburgh, Scotland 4-5 October, 2016

CONFERENCE PROCEEDINGS

M.T. Bamsey, T. Graham, D. Schubert, *"White Paper Initiative Summary & 'Agriculture in Space' – special journal issue within Open Agriculture"*, Agrospace Conference, Poster, Sperlonga, Italy, 26-27 May 2016

V. Vrakking, C. Zeidler, D. Schubert, P. Zabel, M.T. Bamsey, C. Paille, E. Mazzoleni, P. Kern, N. Domurath, J. Kempf, F. Schröder, (2016) *"Greenhouse module for space systems: A lunar greenhouse design."* 7th AGROSPACE Conference, Sperlonga, Italy 26-27 May 2016

I. Schlacht, J. Bernini, D. Schubert, P. Zabel, C. Montanari, G. Ceppi, B. Imhof, R. Waclavicek, B. Foing: *"EDEN ISS: human factors and sustainability for space and earth analogue"*, 67rd International Astronautical Congress, Guadalajara, Mexico, 26-30 September, 2016

P. Zabel, M.T. Bamsey, C. Zeidler, V. Vrakking, D. Schubert, O. Romberg, *"Current status the EDEN ISS – An Antarctic greenhouse to enhance plant cultivation in space Agrospace Conference,* Sperlonga, Italy, 26-27 May 2016

INVITED TALKS

"Invited speaker session: Adapting to the Novel Environments of LEO and Beyond. Presentation: EDEN ISS: An Antarctic greenhouse to advance plant production in LEO and beyond", American Society for Gravitational and Space Research (ASGSR) annual conference (Oct 2016)

"Bioregenerative Lebenserhaltungssysteme für zukünftige bemannte Missionen", Vorlesung Interplanetare Raumfahrtmissionen, TU Dresden, 15.12.2016

"Wissenschaft und Wohnungswirtschaft - partnerschaftlich in die Zukunft", Vertical Farming Project, 8. Mitteleuropäischer Wohnwirtschaftlicher Workshop 23.11.2016

POSTERS

A. Lopez, V. Vrakking, C. Zeidler, D. Schubert: *"VF 2.0: A Vertical Farming Concept"*, Agrospace Conference, Poster, Sperlonga, Italy, 26-27 May 2016

M.T. Bamsey, P. Zabel, D. Schubert, E. Kohlberg, D. Mengedoht *"EDEN ISS: Providing fresh food to overwintering Neumayer Station III crews and long duration missions"*, COMNAP Symposium 2016 'Wintering-over challenges', Goa, India

C. Dong, M. Mohamad, M.T. Bamsey, D. Schubert, *"New modified aeroponic cultivation using ORBITEC system and species selection for the Antarctic greenhouse in DLR-EDEN team"*, Agrospace Conference, Poster, Sperlonga, Italy, 26-27 May 2016

C. Dong, M. Mohamad, M.T. Bamsey, B. Morrow, J. Wetzel, D. Schubert, *"New modified technologies for ORBITEC plant growth systems"*,46th International Conference on Environmental Systems, Vienna, Austria, 10-14 July, 2016

C. Patel: *"Air and Water Considerations for the Integration of Extraplanetary Habitats and Greenhouses"*, Agrospace Conference, Poster, Sperlonga, Italy, 26-27 May 2016

P. Delmotte, P. Zabel, D. Schubert: *"Micro-Tina cultivation using C.R.O.P. solution"*, Agrospace Conference, Poster, Sperlonga, Italy, 26-27 May 2016

P. Delmotte, P. Zabel, D. Schubert: *"Micro-Tina cultivation using C.R.O.P. solution"*, 46th International Conference on Environmental Systems, Student Poster Competition, Poster, Vienna, Austria, 10-14 July, 2016

I. L. Schlacht, J. Bernini: *"EDEN ISS Human Factors"*, Agrospace Conference, Poster, Sperlonga, Italy, 26-27 May 2016

A. Mohamad, V. Vrakking, M.T. Bamsey, D. Schubert, *"3D Printed aeroponic tray nutrient delivery system for bio-regenerative life support systems."* 6th International Conference on Environmental Systems, Vienna, Austria, 10-14 July, 2016

DIPLOM-/ MSC.-/ BSC.-THESIS

C. Patel: *"Gardeners of Galaxy: the Air and Water Considerations for the Integration of Extraplanetary Habitats and Greenhouses"*, (2016), Master Thesis, University of Cincinnati

A. Santos: *"Failure Analysis of EDEN ISS Antarctic Greenhouse Module with consideration of risk and space strategies with outlook to future space-based bioregenerative life support systems"*, (2016), Master Thesis, Instituto Superior Técnico de Lisboa

M. Mauerer: *"C.R.O.P selection and horticultural management for greenhouse modules as an integrated part of human outposts on Mars, 2016"* , Humboldt-Universität zu Berlin

REPORTS (INTERNAL/EXTERNAL)

D. von Borell du Vernay: *"Adaptation of the MEC Plant Growth Model for an Antarctic Greenhouse"*, (2016), TU Dresden

C. Zeidler, V. Vrakking, A. Lopez, E. Denkhaus, D. Schubert: *"Vertical Farming 2.0: A Vertical Farming Concept"*, Internal Report, Bremen, Germany, 2016

SPECIAL

D. Schubert: Acted as reviewer for ICES: *"The Melissa GreenMOSS Prelimenary Design Stdudy: a Greenhouse Module on the Lunar Szurface"*, G. Booscheri et al., 46th International Conference on Environmental Systems, Vienna, Austria, 10-14 July, 2016

M.T. Bamsey: Guest editor: Open Agriculture - Topical Issue: *"Agriculture in Space"*

M.T. Bamsey: Session chair, Agrospace 2016, Sperlonga Session: *"EDEN ISS – Analogue Mission to Antarctica"*

D. Schubert: Organisation of the *"European-Chinese Collaboration Workshop (ECCW) on Closed-loop Technologies for Space, Antarctica and Urban Areas"* hold during the Agrospace Conference 2016, Sperlonga Italy and Bremen (Germany)

D. Schubert: Session chair: Agrospace 2016, Sperlonga Session: *"Update on Space Greenhouse Research & Industry Perspective"*

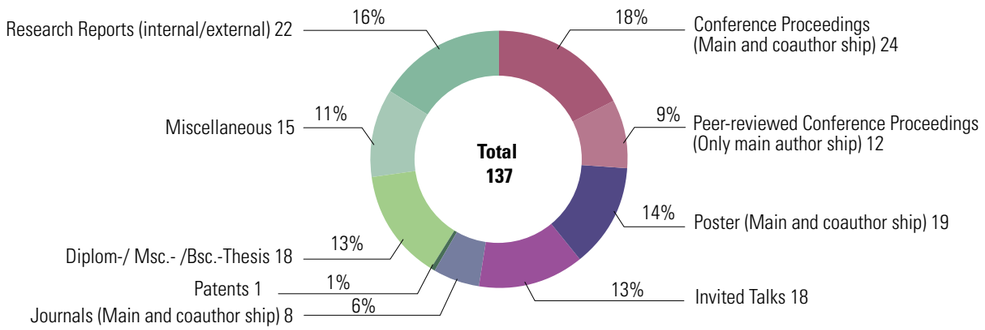
M.T. Bamsey and T. Graham, *"M. Editor's Note for the topical issue 'Agriculture in Space', Open Agriculture topical issue: Agriculture in Space"*, 2016 Vol. 1

D. Schubert et al. White Paper: *"The Space Agriculture Endeavour, Open Agriculture topical issue: Agriculture in Space"*, 2016 Vol. 1

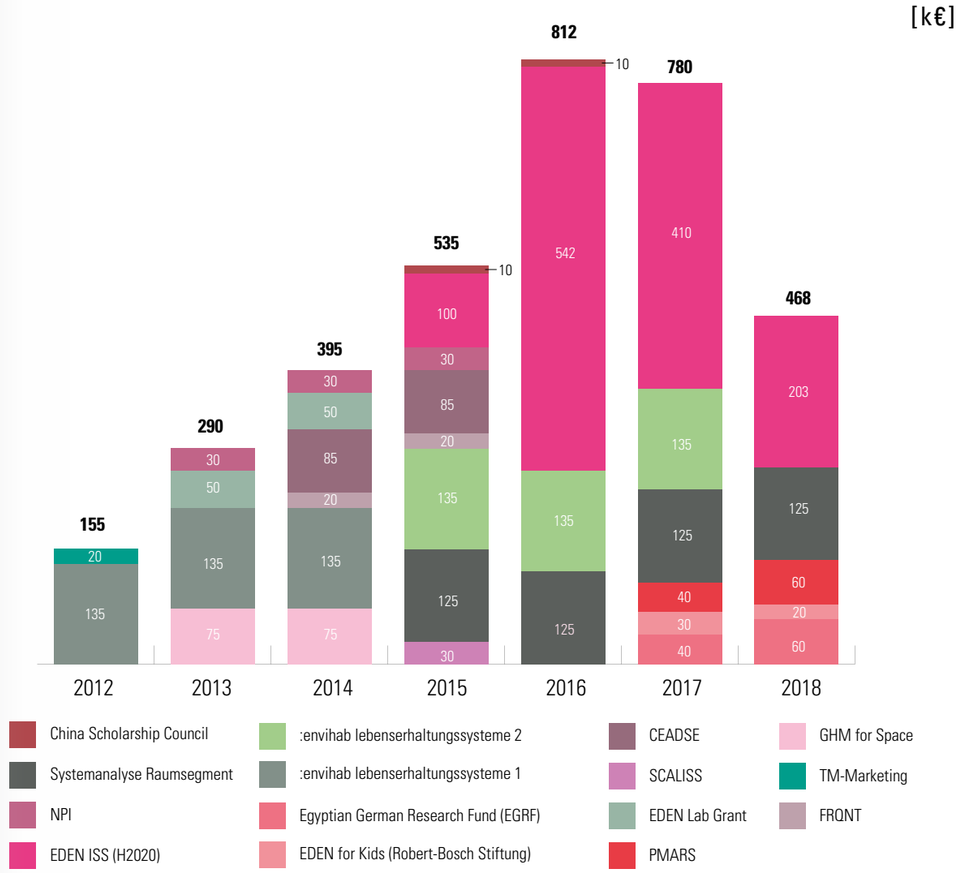
SUMMARY KEY FIGURES

PUBLICATIONS & KEY FIGURES 2011-2016

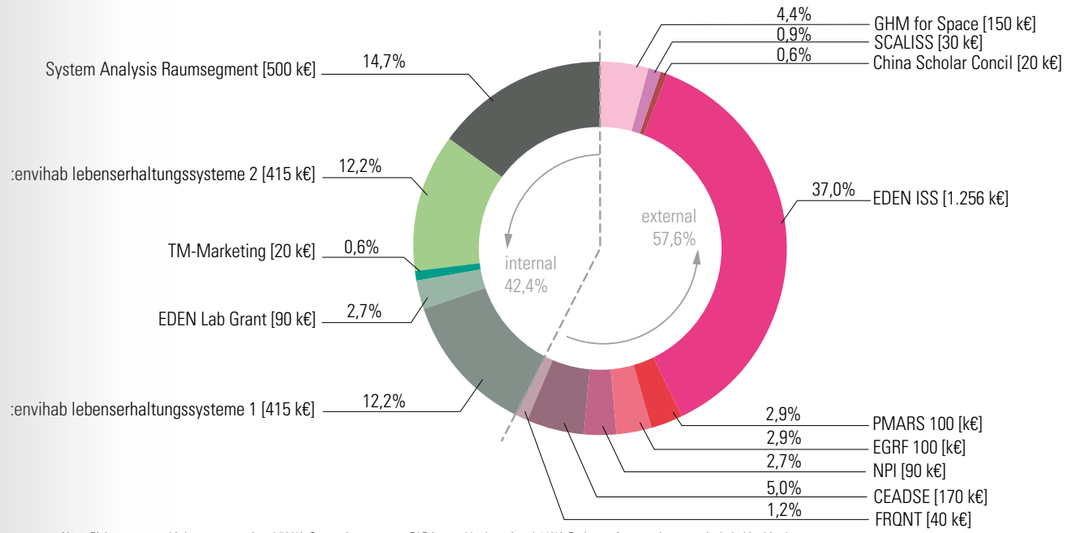
TOTAL PUBLICATIONS & KEY FIGURES 2011–2016



BUDGETS OVERVIEW & FORECAST 2012-2018

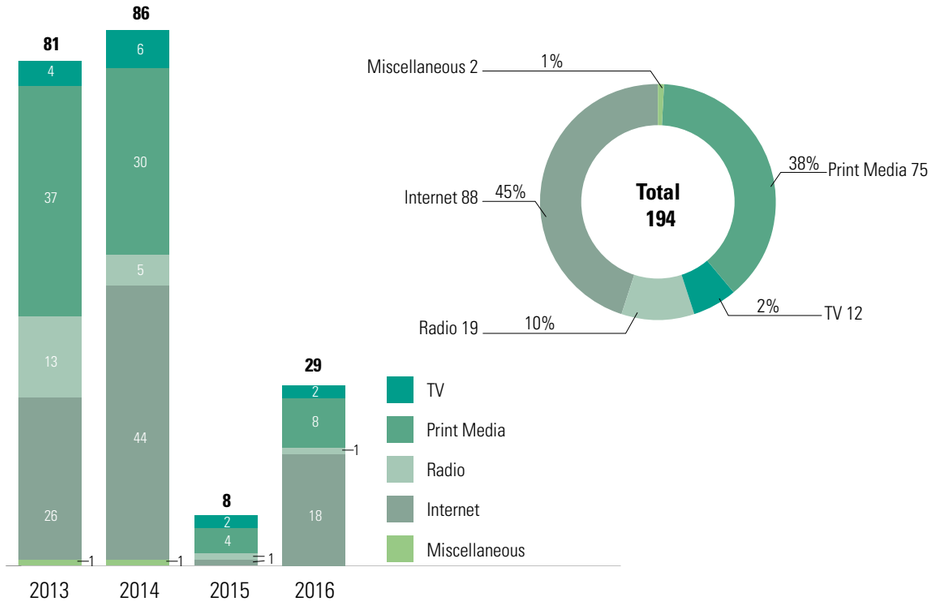


TOTAL BUDGETS DISTRIBUTION 2012-2018 [in k€]

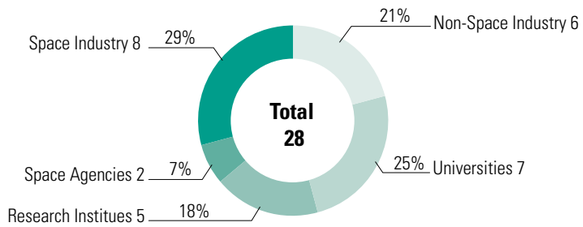


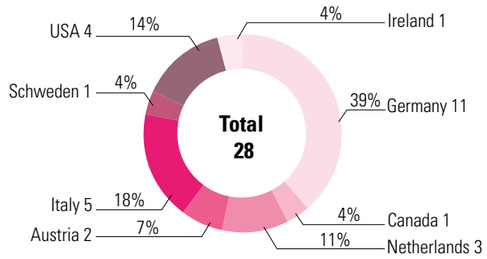
Note: Pink represents third-party money (total 56%); Green pies represent DLR internal budgets (total 44%); Budgets of proposals are not included in this chart.

MEDIA ACTIVITIES 2013-2016 (TOTAL AND YEARLY DISTRIBUTION)

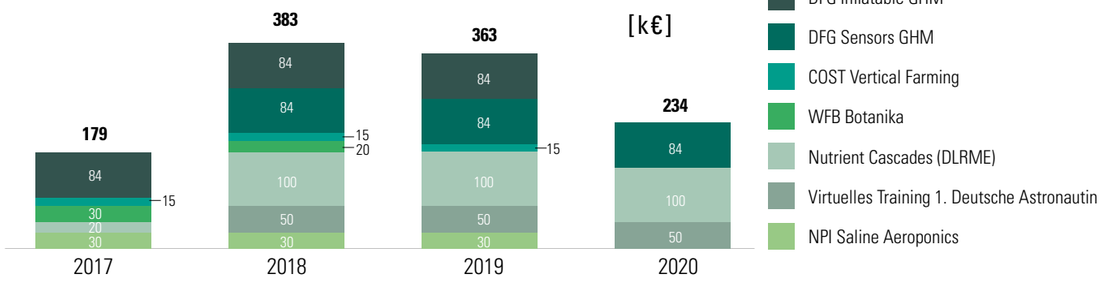


RESEARCH & NETWORK PARTNERS





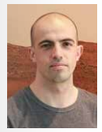
PENDING PROPOSALS



THE EDEN STUDENTS

Without the assistance and help of highly-motivated students, the success of the EDEN Initiative would not have been possible! Therefore the entire EDEN team would like to say thank you. See below what the student's tasks were and what they are doing now:

Amin Mohamad is an aerospace engineering student studying at University of Bath, UK. He did a 12 month placement year with EDEN team as part of his undergraduate study. Amin worked mainly on parts design, operating the EDEN 3d printer, hardware installation and testing. Some of his main projects were to develop new aeroponic tray design and supporting parts for EDEN's experiments, installing LED panels, operating and maintaining ORBITEC Veggie unit. Amin has returned to University of Bath to continue his studies for another 2 years.



Antonio Santos is an aerospace engineering student working on his Master at the Instituto Superior Técnico, Lisbon, Portugal. He served as a Master's Thesis student at DLR from March to August 2016, his topic outlining failure mode, effects and criticality analysis on the on the EDEN ISS project. He is finishing in October 2016, aiming to apply for System Engineering jobs.

Mareike Mauerer is a horticultural scientist who graduated from Humboldt University of Berlin with a MSc in Process and Quality Management in Agriculture and Horticulture. During her time at DLR she worked on her master's thesis on C.R.O.P selection and cultivation specifics. In the context of her thesis she also performed an acceptability study for the EDEN ISS project. Mareike wants to continue researching higher plants in bioregenerative life support systems and plans to do her PhD on a related topic.

Erik Denkhaus holds a Masters in Plant Biotechnology from the University of Stellenbosch, South Africa. During his time at the DLR in Bremen he worked on a spin off idea from the EDEN project and technologies, Vertical Farming. He was part of a team who completed an economic feasibility study conducted in conjunction with the Association for Vertical Farming to raise awareness about the commercial prospects of Vertical Farming and building a commercial Vertical Farm in Europe. This is a great field of research with lots of business potential; in the future he aims to be involved in the main stream adoption of Vertical Farming for local, sustainable and fresh food production.

Pierre Delmotte is a mechanical engineering undergraduate student from the University of Bath, England. During his 12 months internship with EDEN, he helped in the maintenance of the laboratory, testing and installation of new hardware and also some LabVIEW programming. Pierre also presented his work on the C.R.O.P project at the Agrospace and ICES conferences. Pierre has now returned to university for 2 years to finish his Master degree.

Cj Patel is an aerospace engineering student working on his bachelors at the University of Cincinnati in Cincinnati OH. USA. He served as a Master's Thesis student at DLR from January to August 2016, his topic outlining air and water considerations for planetary habitats and greenhouses. He is finishing in his degree in 2017, aiming to apply for graduate school in the area of life support systems or bioastronautics.

Dominik von Borell du Vernay is a mechanical engineering student at the Technical University of Dresden. During his 5 month internship at DLR, he supported the EDEN team with lab maintenance, hardware installation and research tasks. Furthermore, he worked on a seminar paper on the EDEN ISS project. Dominik has returned to DLR in order to write his diploma thesis on life support systems for a lunar outpost.

Alberto Lopez is a Biosystems Engineer graduated from Wageningen University in the Netherlands, with a specialization in farm technology. Before coming to Europe, he worked for three years as a researcher for the Agricultural Engineering School of the University of Costa Rica. At DLR, Alberto worked on the finalization of the Vertical Farm 2.0 Concurrent Engineering study report. His main tasks were analyzing the consistency and general feasibility between the different subsystems and developing the Computer Assisted Design model for visualization. He is currently pursuing a career in Research and Development of novel greenhouse technologies.

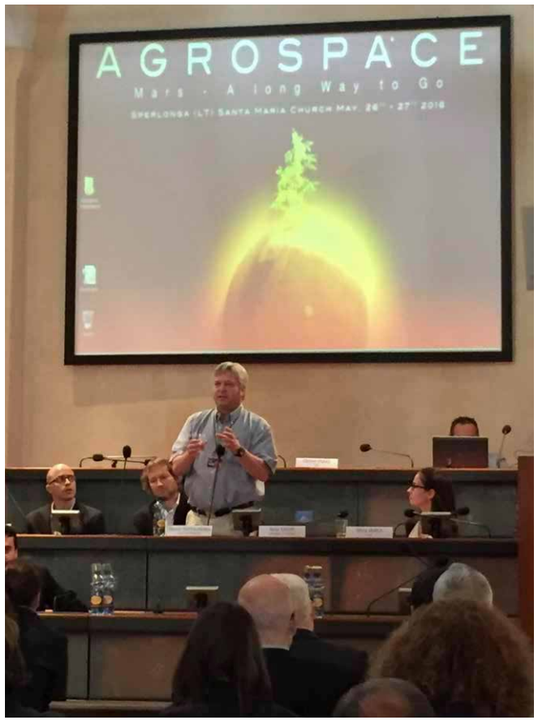
IMPRESSIONS 2016

THE YEAR EDEN GOT GOING...

Dr. Matthew Bamsey presenting Dr. Robert Ferl (UFlorida) with the AIAA Jeffries Award at the 2016 ICES conference

Matthew Bamsey presenting introductory remarks during the Jeffries award presentation

Panel speakers at the 2016 AGROSPACE workshop



Dr. Mike Dixon (UGuelph) presenting at AGROSPACE 2016

The participants of AGROSPACE 2016

A view into the on-going AGROSPACE workshop

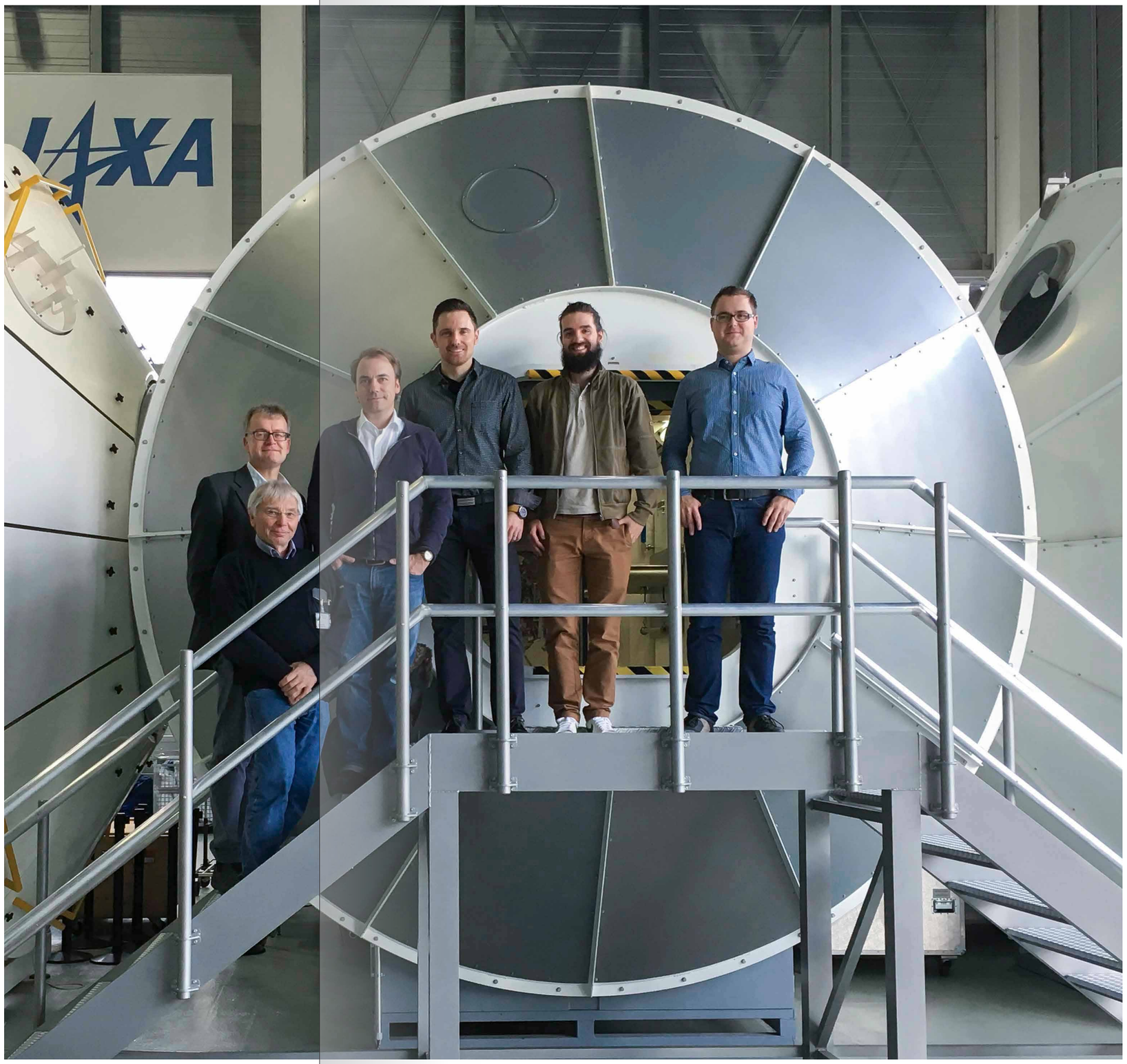
A suite of posters at AGROSPACE 2016, showing the hard work of several EDEN students

Chen Dong with his poster along with Matthew Bamsey following the 2016 ICES poster session

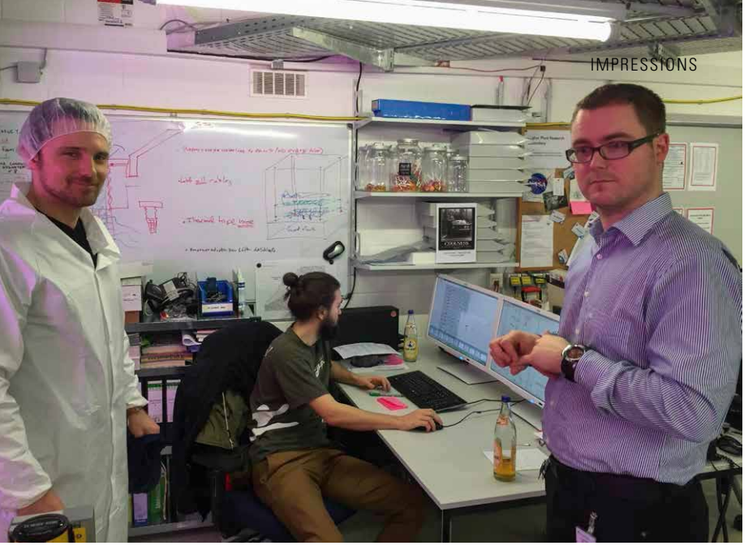
Group picture of the participants at the AVF Summit 2016 in Amsterdam, Netherlands

Conrad Zeidler and Dirk Mengedoht (AWI) following a tour of :envihab in DLR Cologne

20' foot container of the company Urban C.R.O.Ps at the GreenTech 2016 exhibition in Amsterdam, Netherlands



Dirk Mengedoht (AWI), Dr. Eberhard Kohlberg (AWI), Daniel Schubert, Matthew Bamsey, Conrad Zeidler and Paul Zabel following meetings at the ESA European Astronaut Center



Matthew Bamsey, Conrad Zeidler and Paul Zabel in the main room of the EDEN Lab

A ‚full' ORBITEC Biomass Production System for Education within the EDEN Lab

Laboratory activities within the EDEN Lab's Closed-Loop Test Facility

A view into one of the Wageningen EDEN ISS growth chambers illustrating the suite of Heliospectra LED ligths

Three of the EDEN Lab growth chambers under operation

Student Pierre Delmotte testing cameras for use in the EDEN ISS project

Amin Mohamad and Dominik von Borell du Vernay in leak clean up mode within the EDEN Lab

EDEN Lab grown tomatoes

Esther Meinen holding an EDEN ISS growth radish

Amin Mohamad operating the EDEN Lab 3D printer

Chen Dong monitoring plant growth activities in the multilevel plant growth chamber in the EDEN Lab

An EDEN Lab team member ‚reflecting' on cucumber growth within the EDEN Lab

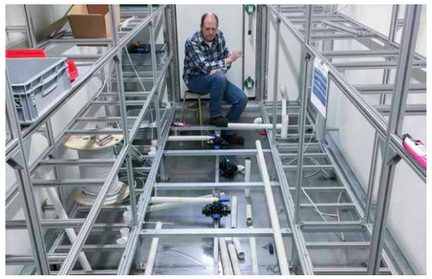
14-year old Rabea Gamgami during her 2 week long school internship in the EDEN lab

Partially installed EDEN ISS nutrient delivery system

A happy project manager during delivery of the EDEN ISS containers

Matthew Bamsey, Ray Wheeler (NASA), Robert Ferl (UFlorida), and Anna-Lisa Paul (UFlorida) during coffee break discussions

EDEN ISS consortium members in discussion during an EDEN ISS CDR break



Dr. Mike Stasiak (UGuelph) during assembly, integration and test activities in the EDEN ISS MTF

EDEN ISS team members during an institute tour

Viktor Fetter (ADS) and Daniel Schubert during a break at the EDEN ISS CDR

Giorgio Boscheri (TASI), Dr. Gene Giacomelli (UArizona), Dr. Tom Dueck (WUR) and Marco Volponi (TASI) in discussion


Bremen und umzu

BILD BREMEN • 09. APRI

„Eden"-Projektleiter Daniel Schubert (40): „Wir züchten hier Pflanzen für den ersten Garten auf einem fremden Planeten"

Vitamine auf Mond & Mars

Forscher züchten Gemüse fürs All

So soll es später im Weltraum mal aussehen

Von MIRCO SEEKAMP

Horn-Lehe – **Das ist nicht nur gesund, sondern soll Astronauten auch gute Laune machen: Das Deutsche Zentrum für Luft- und Raumfahrt (DLR) züchtet Gemüse fürs All!**

Mit dem Projekt „Eden" revolutionieren die Bremer Experten das Leben der Forscher im Weltraum! Sie entwickeln unter Strahlung im Hochsicherheits-Labor Gewächshäuser, in denen an Bord der Internationalen Raumstation ISS oder in einer Rakete zum Mars frisches Obst und Gemüse wächst.

Projektleiter Daniel Schubert (40): „Wir arbeiten an einem geschlossenen Kreislauf, der aufbereiteten Urin, Abwasser und Kohlenstoffdioxid umwandelt." In sauberes Wasser, Sauerstoff, Tomaten, Paprika, Gurken und Salat. Und das ohne Tageslicht, echte Erde oder Insekten – nur auf Nährstofflösung und unter roten und blauen LED-Lampen.

Irre: Es schmeckt wunderbar und ist genauso gesund wie echtes „Erd"-Gemüse!

Vorteil: Es stärkt auch die Psyche der Astronauten. Schubert: „Wenn jemand für drei Jahre auf Marsmission geht und dauerhaft nur von Technik umgeben ist, sehnt er sich nach etwas Grünem." Gleichzeitig können u. a. Abwässer recyclet werden. Das spart den teuren Transport durchs All für stolze 30 000 Euro pro Kilo.

Im August 2015 veröffentlichten NASA-Forscher Fotos vom ersten Salat im Universum (BILD berichtete). Darüber lacht Schubert: „Das war doch bloß anspruchsloser Kopfsalat. Da geht längst viel mehr!"

2017 fliegen die ersten Tomatenpflanzen aus Bremen ins All, und die Arktis-Forscher vom Alfred-Wegner-Institut in Bremerhaven testen das Gemüse im ewigen Eis. Cool!

Mit einem Messschieber prüft der Forscher das Gemüse. Im Becherglas sind kleine Tomaten

Ohne Erde und unter künstlichem Licht wachsen knackige Gurken

Dieser Container simuliert den Weltraumgarten auf der Neumayer-Station vom Wegener-Institut

Foto: PHILIPPE WEISSBRODT

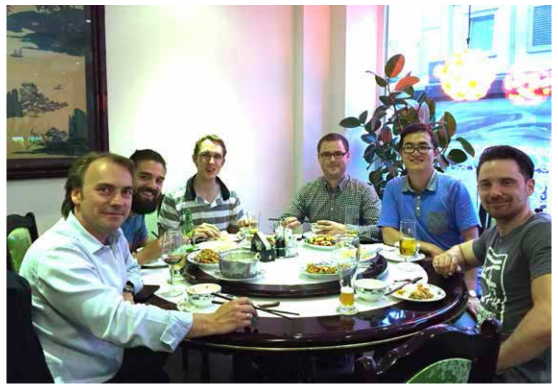
Fotos: CHRISTOPH SEEMANN

The EDEN team in the news


Vincent Vrakking, Chen Dong, Conrad Zeidler during an EDEN team social gathering


Paul Zabel enjoying the warm weather during an EDEN team social gathering


A pre-AGROSPACE workshop dinner for EDEN ISS conference participants


The EDEN team during a thank you and goodbye dinner for Chen Dong

IMPRESSIONS


EDEN team members enjoying some good italian food


Italian pizza during AGROSPACE 2016. The name? Pizza EDEN!


Matthew Bamsey and Chen Dong in Brussels prior to an EDEN ISS status meeting with the European Commission

EDEN ISS students Pierre Delmotte, Antonio Santos, Amin Mohamad and Alberto Lopez showing off their AGROSPACE 2016 conference t-shirts

Some of the members of the 2016 EDEN team

AGROSPACE

to sow into the future, to harvest in the present

WHITE PAPER

Release Date 26th of May 2016

The Space Agriculture Endeavour

This white paper was initiated during the 6th International AgroSpace Workshop, held in Sperlonga, Italy from May 22nd – 23rd, 2014 and was subsequently refined in the months following. We are members of international research centers, academia and the space industry, who cooperate to design, develop and test greenhouse-based Bio-regenerative Life Support Systems (BLSS). We reflect a multidisciplinary group of international experts representing aerospace engineering, plant science, horticulture, microbiology, food science, medicine, architecture and psychology. The purpose of this position paper is to layout the advantages and challenges of utilizing higher plants as an essential part of BLSS for long-duration human space missions. The white paper's objective is to convince decision-makers within government and space agencies to invest in this development pathway and to pave the way to a fruitful future of space exploration and terrestrial growth.

Sustainable Presence in Space and on Earth

Sustained human presence in space requires the development of new technologies to maintain environment control, to provide water, oxygen, food and to keep astronauts healthy and psychologically fit. Furthermore, the logistics of mission resupply limits human exploration in space. BLSS in conjunction with in-situ resources will initially reduce and ultimately eliminate consumables from the logistics chain. Minimizing this need for resupply while ensuring human safety will allow astronauts to travel further and stay longer in space than ever before. While physical/chemical life support systems would form the back-bone as a fallback strategy, the BLSS would expand to eventually become the prime system ensuring sustainable life support for long-duration missions.
Many international advisory groups are highlighting the necessity to further develop such regenerative systems (NASA, 2010, *Technology Frontiers: Breakthrough Capabilities for Space Exploration'*; European Science Foundation, 2012, *THESEUS Roadmap*; ISECG, 2013, *Global Exploration Roadmap*).

Unrivaled Features of Plants

The cultivation of higher plants can contribute to all major aspects within BLSS and represents an all-in-one-approach, not accomplished by any single physical/chemical system.
The most apparent advantage is the provision of food. Fresh food provides essential vitamins, minerals and other useful macromolecules such as useful bioactive compounds to support crew health, and function this way as countermeasures for the stresses associated with deep space exploration.
Considering the symbiotic relationship between humans (carbon dioxide emitters) and plants (carbon dioxide absorbers), plant growth modules will also provide valuable oxygen to the crew. NASA studies have demonstrated that the oxygen needs of a single crew member could be met by approx. 10-20 m^2 of plant area.
Through the exploitation of plant evapotranspiration, the deployment of plants can furthermore contribute to wastewater recycling. Recent research from the Lunar Greenhouse test stand at CEAC (University of Arizona) has shown that 12 m^2 of plant area could generate up to 21 L of potable water per day. Research at the Chinese's Lunar Palace 1 test stand at Beihang University showed that 23 m^2 of plant area can generate up to 60 % of dietary needs for one person.

Astronaut physical and psychological well-being is vital, especially during long duration missions with constant isolation in a highly-integrated machinery environment, including the dependency on these machines. The visual appearances of plants ('nature') as well as activities with them ('gardening') and associated design and architectural solutions can greatly enhance the psychological well-being of the crew.
From a long-term perspective, bio-plastic, latex, or other high value compounds that can be generated from plants, will also help reduce consumables and increase mission autonomy. Transforming bio-plastics into granulates and using them with the latest 3D printing techniques, opens a wide variety of in-situ production capabilities.

Accomplishments and Challenges

Significant investments in unique research infrastructure like Controlled Environment Agriculture (CEA) laboratories, plant test stands, and analogue test sites were completed in recent years to investigate essential aspects of (semi) closed-loop plant cultivation and to develop the required plant cultivation technologies.
Through the implementation of CEA technologies that carefully control and optimize the provision of nutrients (e.g., H_2O, pH, electrical conductivity, as well as soilless cultivation), environmental conditions (e.g., temperature, relative humidity, concentration of CO_2 & O_2), and light, including spectral composition (e.g., red, blue, UV), it is now possible to achieve higher yields and shorter growth cycles. Through CEA, even the exact control of food quality is possible (e.g., phenotype, taste, enrichment of useful substances => functional food).
Nevertheless, challenges exist in developing cultivation systems. Several key technologies necessary for space-based plant production are not yet space-qualified or remain in early stages of development. In order to achieve higher Technology Readiness Levels (TRL), higher contributions and budget allocations in respective projects and programs need to be assigned.
Technology gaps include: self-regulating multi-nutrient delivery systems, low mass and actively-cooled LED lighting systems, efficient approaches for capturing and delivering solar light, low-energy water recovery systems, semi-automated planting and harvest systems to minimize crew time, and crops tailored specifically for the constraints of space (e.g., dwarf growth, high harvest index, high productivity). Furthermore, post-harvest procedures including food safety assays need to be developed and tested.

Terrestrial Benefits

The production of plants with resource-efficient and space-based regenerative principles has great impact on commercial agriculture and contributes to many different socially important challenges that the world faces today (e.g., eco-intensification of production systems, sustainable management of natural resources, contributions to a sustainable food chain and a global food security system).
Climate change is affecting food production through desertification, transforming once fertile lands into inhospitable deserts. Modified greenhouse modules, located in desert regions, can provide an opportunity to utilize these areas for agriculture. Greenhouses optimized with closed-loop habitat technology excel in this purpose due to their low water requirements and waste outputs compared to traditional agriculture. The ability to grow crops throughout the whole year, and minimize crop losses due to drought, insects) and diseases, make these greenhouse modules a potential solution for agriculture in other hostile climates (e.g. polar areas) as well as in remote location (offshore facilities, remote villages, islands, and isolated work sites). Furthermore, critical areas of need include ensuring a safe food supply under emergency conditions following natural disasters (hurricanes, earthquakes, floods), humanitarian crises (famine, refugee camps), and political unrest (military and humanitarian support roles).
One of the recent mega-trends in society is urban agriculture, where vertical farming is a proposed cultivation technique involving large-scale agriculture in urban high-rises or "farmscrapers". These buildings would be able to produce fruits, vegetables and other consumables like pharmaceutical plants (e.g. molecular farming) throughout the entire year independent of season, climate, region and sunlight, offering high yields and nutritional values, while using 98% less water than traditional open field agriculture. This technology will not only save water, fertilizer, and space, but reduces or eliminates discharge into the environment as well. Most importantly, it will be a key technology to secure future food supply of cities while decreasing their ecological footprints.

Public Engagement

The fascination of space agriculture is something that the spectrum from young students to grandparents can relate. Plants are something that nearly all people can connect with, whether it is from having a direct "green thumb" experience or simply as a consumer of fruits and vegetables, the importance is obvious. Combining plant growth with space exploration further adds to this fascination and this has been used by a number of countries and leaders in educational curriculum development as a tool to motivate learning across any number of the associated subjects (e.g., mathematics, biology, physics, logistics, sustainability). This has been explicitly demonstrated through highly successful space learning programs such as Tomatosphere, which in Canada and the US alone has reached over 16000 classrooms. We understand the importance and the benefits for the continuation and further enhancement of programs such as the Canadian Space Agency and University of Guelph Tomatosphere project and other notables such as DLR_School_Lab, University of Arizona Lunar Greenhouse Project, the Beihang University Lunar Palace 1 outreach program, and the NASA led International Space Apps Challenge.

Conclusion

Bio-regenerative air revitalization, water recycling, waste management and the sustainable production of nutritious food for human survival in space is a challenge that needs to be overcome, not only for space, but also for terrestrial applications.

This research direction can lead to resource-efficient, sustainable living and strengthen the global food, energy and waste recycling industries. The imperatives for this research endeavor are critical and challenging, and the requirement to adapt the CEA technologies for the space sector adds even further challenge. Nevertheless, by investing in this research, new cultivation approaches in producing food and other useful bio-products can be achieved in a resource-efficient manner.

The overall goal is the adaptation, integration and demonstration of higher plant cultivation technologies and operation procedures for safe food production on-board present and future space vehicles (starting with ISS) as well as in future, long-term planetary outposts.

Out of necessity, these actions have to be initially performed on the ground, both in, laboratory environments as well as in extreme environment test beds, such as highly-isolated Antarctic research stations. That is why we believe that much of the essential background technology exists to move forward towards exploration, and we are committed to seeing large-scale, integrated systems evaluated under mission relevant conditions with an analogue mission greenhouse (e.g. Antarctica) in 2017, a full-rack plant growth payload on ISS by 2021, and large-scale payload on either ISS or the lunar surface by 2025. We are hopeful that funding mechanisms in the space agriculture domain will permit these activities and their associated terrestrial benefits to be realized.

Signatories on next page

The following signatories support the principles described in the Space Agriculture Endeavour White Paper.

S. Rossignoli, President, Aero Sekur SpA, Italy

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C. Lobascio, Head of Space Flight, Environment & Habitat, Thales Alenia Space Italia

L. Briganti, Head of Life Science & Commercial Projects, Airbus Defense & Space

D. Schubert, EDEN Team Leader, Institute of Space Systems, German Aerospace Center, Germany

P. Zamprelli, Business Director, Orbital Technologies Corporation (ORBITEC), USA

Prof. Dr. G. A. Giacomelli, Director, Controlled Environment Agriculture Center; University of Arizona, USA

Prof. Dr. M. Dixon, School of Environmental Sciences Controlled Environment System Research Facility, Canada

Dr. M. Kliss, Branch Chief, Bioengineering Branch, AMES Research Center, NASA, USA

Prof. A. Tikhomirov, Executive Director of International Center of Closed Ecosystem, Institute of Biophysics, Institute of Biophysics, Russia

Dr. B. Imhof, Managing Director, Space Systems Design, LIQUIFER System Group, Austria

Prof. L. Hong, Institute Leader; Institute of Environmental Biology and Life Support, Beihang University, China

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J. Popein, CEO, Lumeolux Corp., Canada

T. Bongartz, Innovation Manager Horticulture Business, Special Lighting Innovation Management, OSRAM GmbH

Issue 3
Bremen, March 28th, 2017

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Deutsches Zentrum für Luft und Raumfahrt e.V.
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Institute of Space Systems
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DLR at a Glance

DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.
DLR has approximately 8000 employees at 16 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Goettingen, Hamburg, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.
DLR's mission comprises the exploration of Earth and the Solar System and research for protecting the environment. This includes the development of environment-friendly technologies for energy supply and future mobility, as well as for communications and security. DLR's research portfolio ranges from fundamental research to the development of products for tomorrow. In this way, DLR contributes the scientific and technical expertise that it has acquired to the enhancement of Germany as a location for industry and technology. DLR operates major research facilities for its own projects and as a service for clients and partners. It also fosters the development of the next generation of researchers, provides expert advisory services to government and is a driving force in the regions where its facilities are located.

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