Food Production within a Container by Recycling Urine and Organic Waste

Dominik Quantius*, Daniel Schubert*, Jens Hauslage**, Kai Waßer**, Gerhild Bornemann**, Thorsten Kraska***

*German Aerospace Center (DLR)
Institute of Space Systems
Department of System Analysis Space Segment
Bremen, Germany

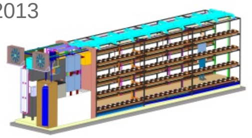
**German Aerospace Center (DLR)
Institute of Aerospace Medicine
Cologne, Germany

***Agricultural Faculty, University of Bonn, Germany

Telephone: +49 421 24420-1109
Telefax: +49 421 24420-1120
E-Mail: Dominik.Quantius@dlr.de

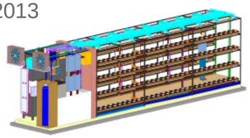
Knowledge for Tomorrow

DLR



Content

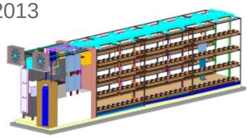
- Study Goals
- Concurrent Engineering Study
- Container Design
- Outlook



Study Goals

- Design an accessible shipping container in which a food production system is integrated with the following units:

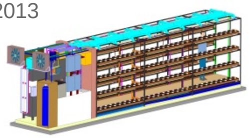
    - Higher plant segment
    - Bio-filter system
    - Urine segment



Study Goals

- Layout of the CROP-system including subsystems for the container
- Dimensioning of units (size, power, cycle of materials (water, urine, fertilizer, biowaste)), sensors, tanks, pumps;
  design driver: maximize plant area!
- Accommodation of units

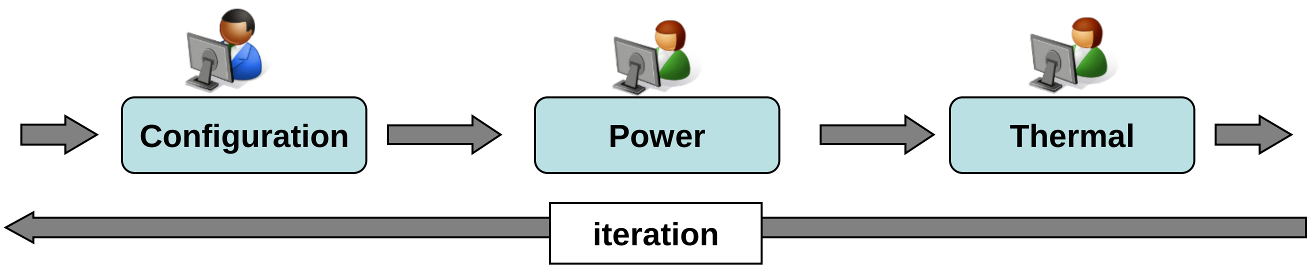
- Requirements for the container (e.g. isolation, windows, structure)
- Operation scenario
- Risk and cost evaluation



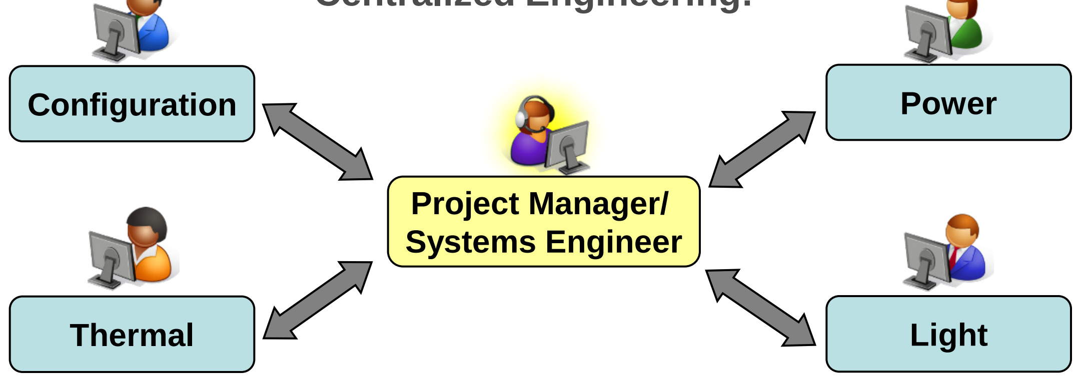
Concurrent Engineering … is not …

- Conventional Design / Engineering Processes

Sequential Engineering (with iterations):



Centralized Engineering:



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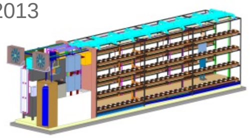
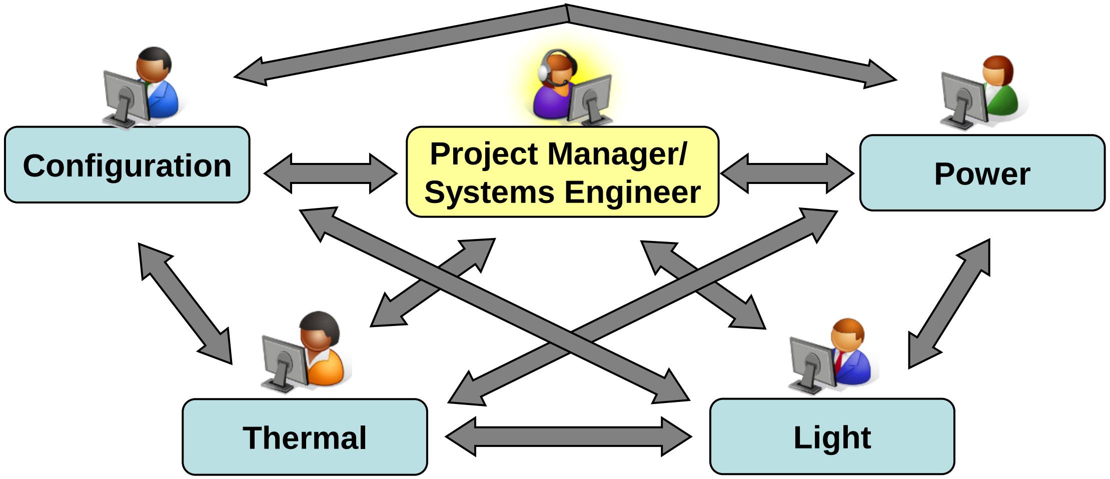
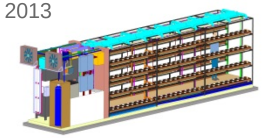


Concurrent Engineering

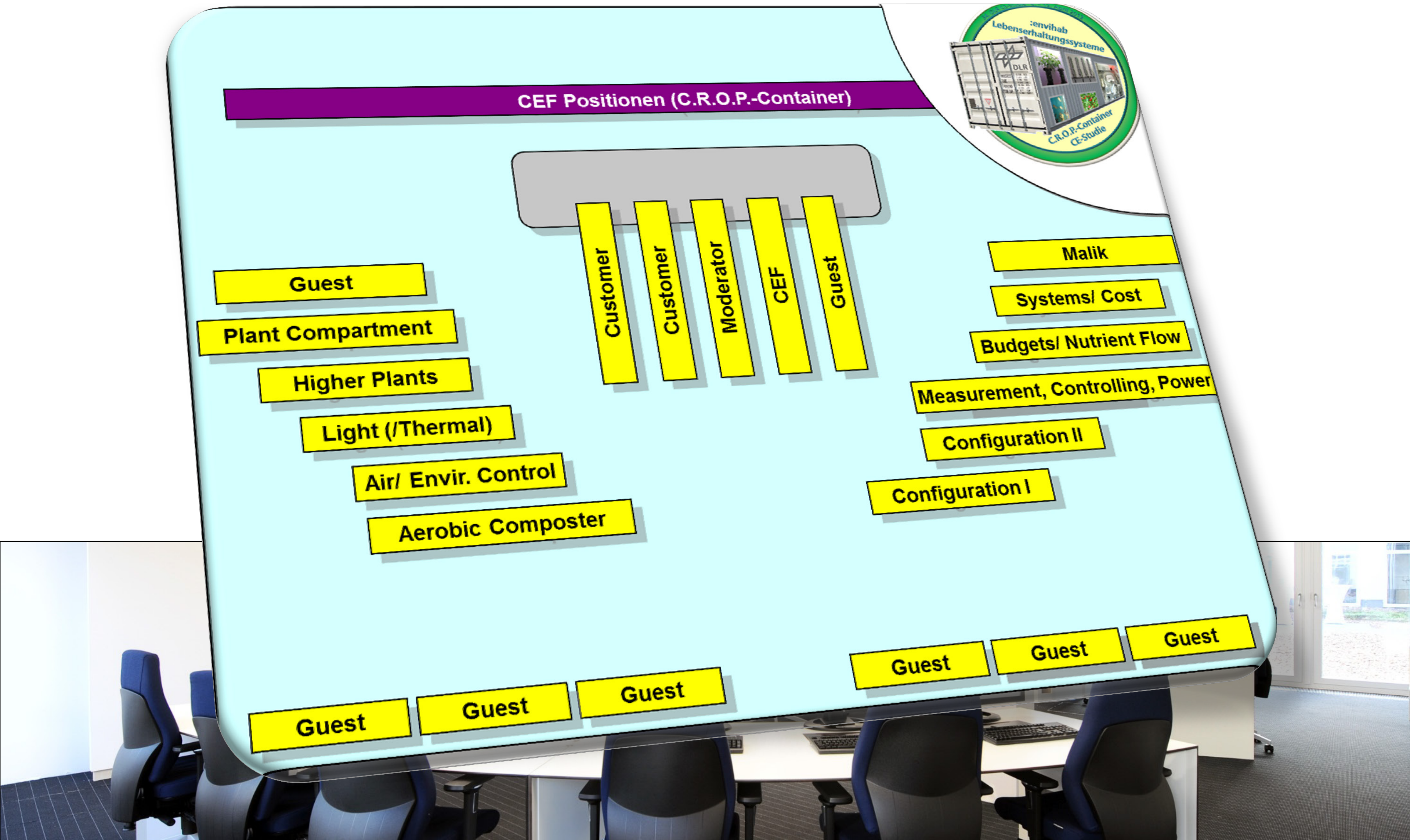
- Concurrent Design / Engineering Process

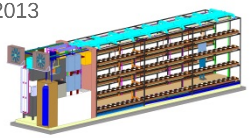


- The five key elements:
  - Interdisciplinary expert team
  - CE - process
  - Integrated Design Model
  - Facility / Infrastructure
  - Tools (e.g. S/W; Multi-Media)

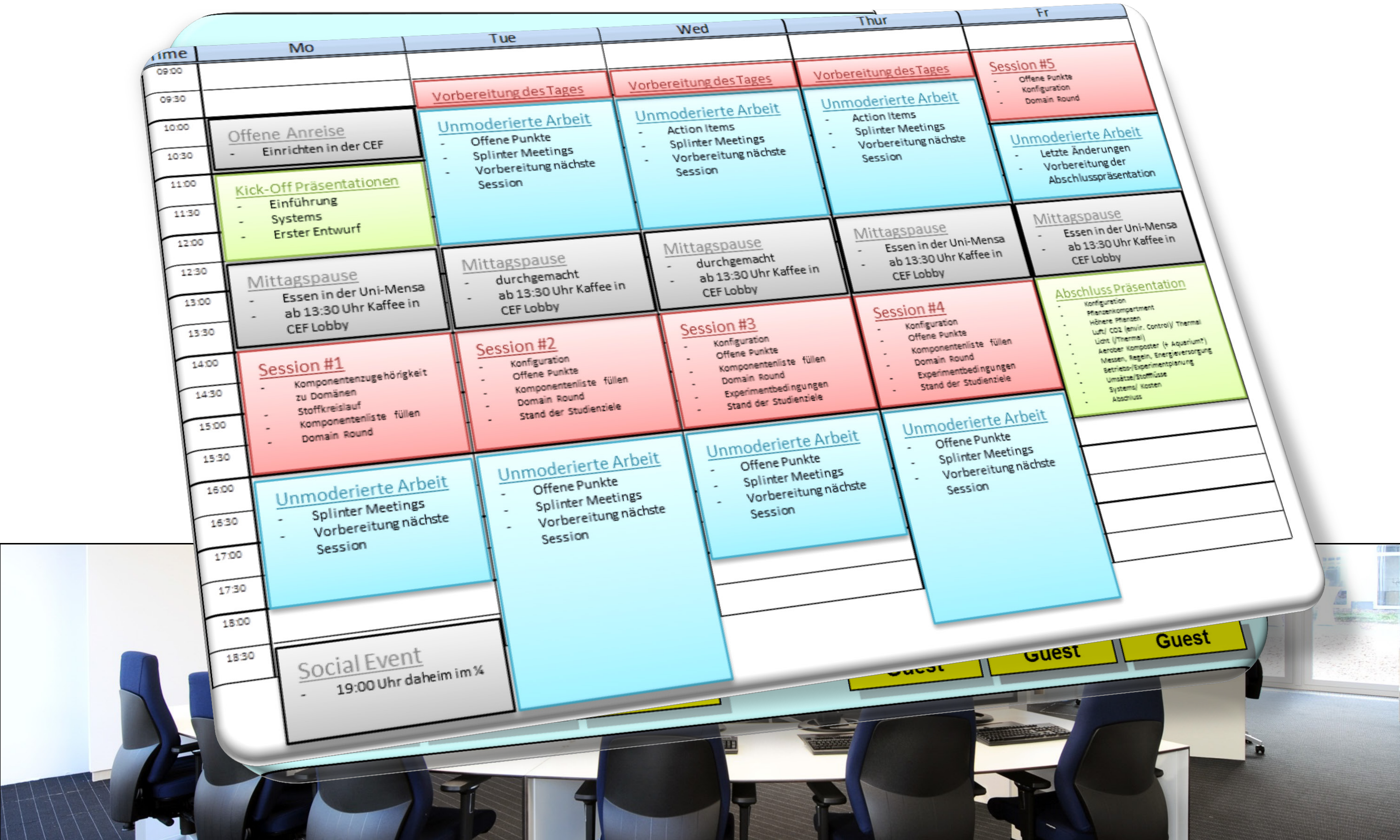


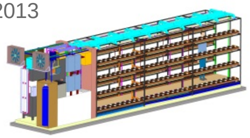
Concurrent Engineering



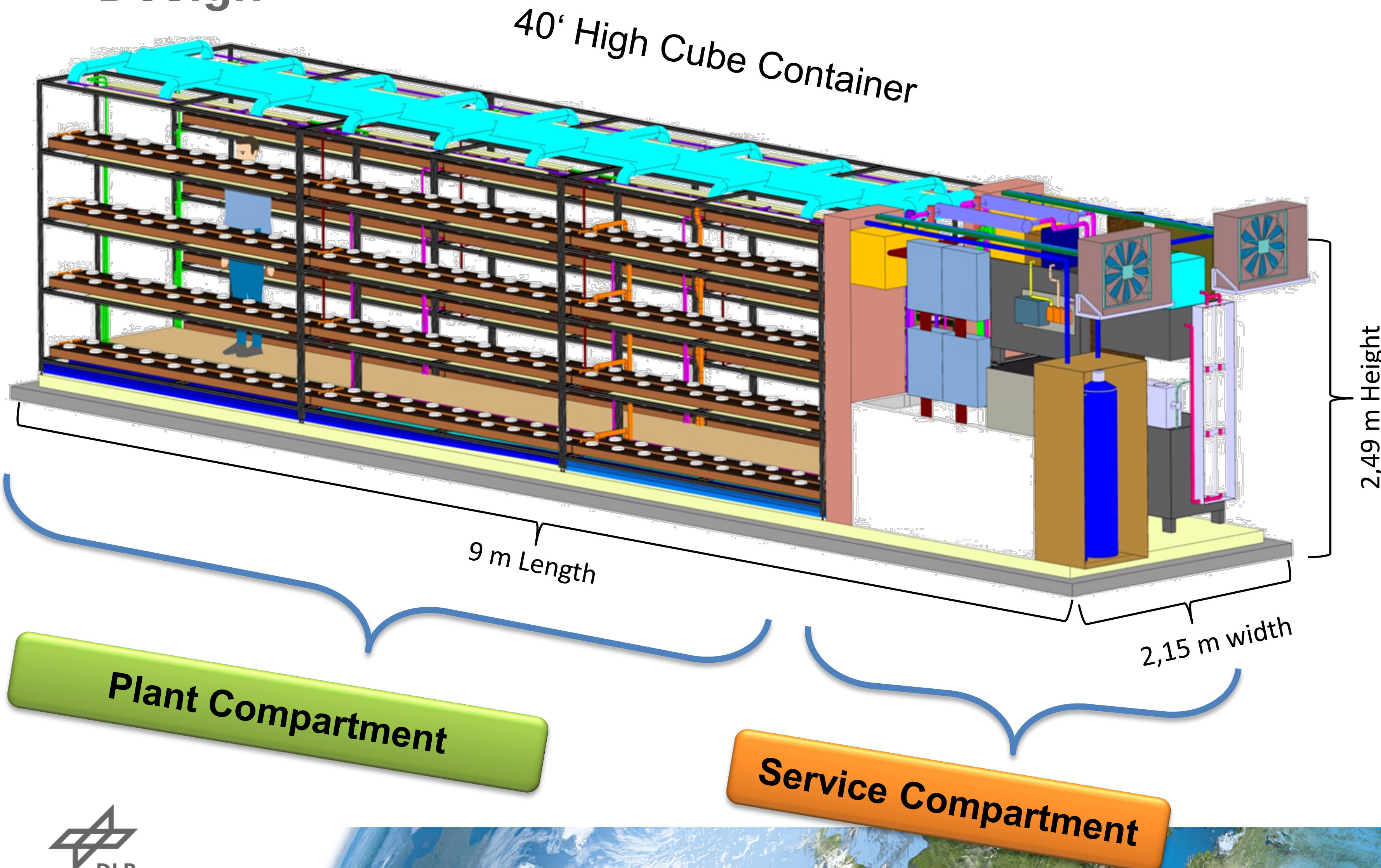


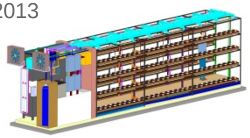
Concurrent Engineering





Design


40‘ High Cube Container
2,49 m Height
9 m Length
2,15 m width
Plant Compartment
Service Compartment

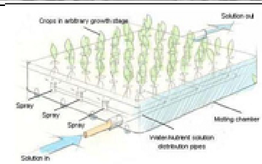
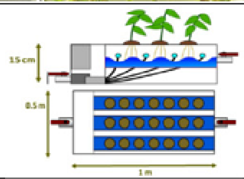


Design

Plant Compartment

Options:

- Aeroponic (no!)
- Deep water (no!)
- NFT (no!)
- Flooding (optional)
- Continuous flow (yes!)
- Drip irrigation (optional)

Study Reference	Considered Irrigation System/s	Image
NASA Steckler UA-CEAC Lunar Greenhouse [40]	Cable culture hydroponic system. Washable, low mass, no substrate required. Plants are inserted into a continuous tube that is suspended by aircraft cable attached only the ends of the row. Nutrient water fed into the tube at each end of the row, flowed through the plant root system, discharged and recycled, similar to the Nutrient Film Technique (NFT)	
ESA OGEGU [41]	Considered irrigation systems with medium (flood and drain, dripping irrigation) were discarded for mass and risk. Aeroponics was chosen among NFT, Aeroponics, and Deep Water culture for low mass	
Mc Murdo Greenhouse [42]	NFT system, with electric conductivity and pH hand-adjusted. Perlite and vermiculite were used as growing media.	
Amudsen Scott SPFGC [29]	Recirculating hydroponic system without root zone substrate, except for a 25 mm germination/transplant seedling cube. Dissolved oxygen in the nutrient solution not measured, but oxygenation was provided by air introduced through bubblers (0.01 m^3 min^{-1}) directly in the nutrient solution storage	
TAS-I SEEDS Lunar FARM [35]	Soil discarded; considered hydroponic, aeroponic and zeoponic cultivation methods. NFT chosen for compromise between mass and needed water buffer	
MELiSSA UAB [43]	Nutrient Film Technique was selected and implemented.	

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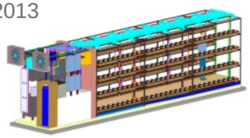
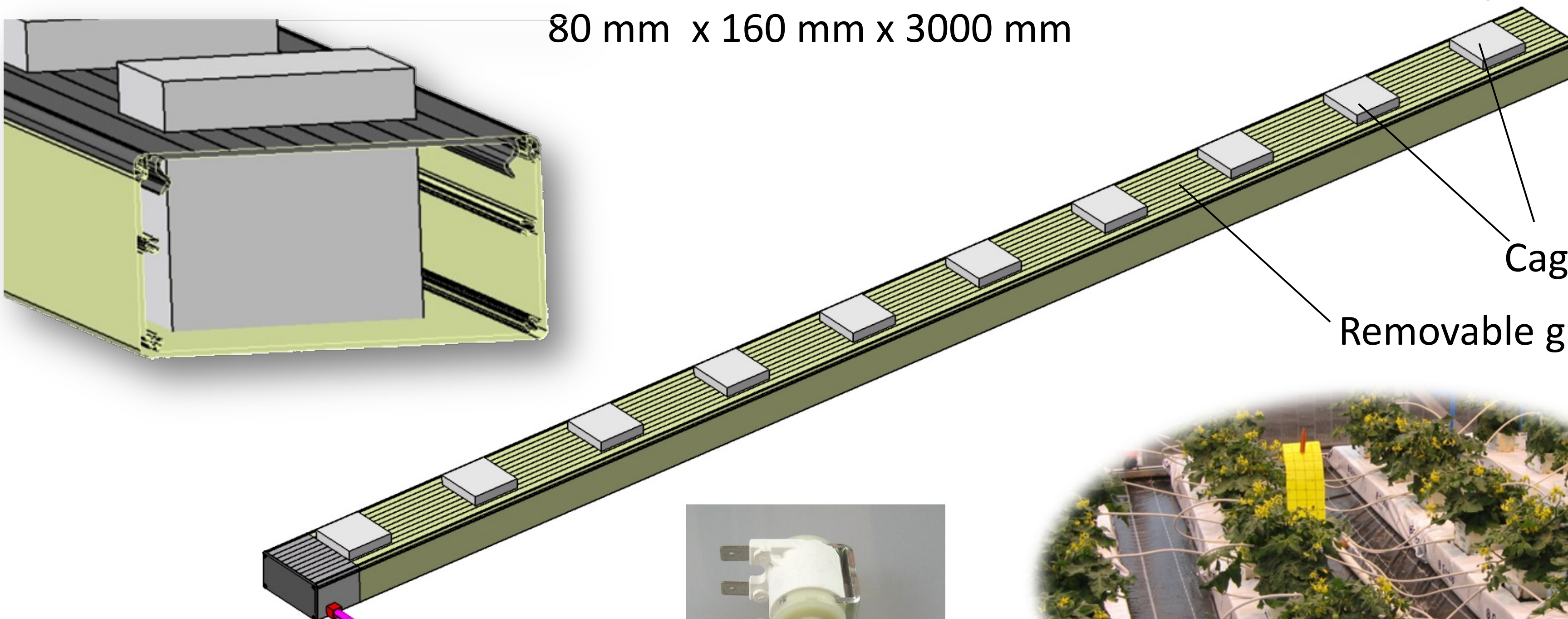


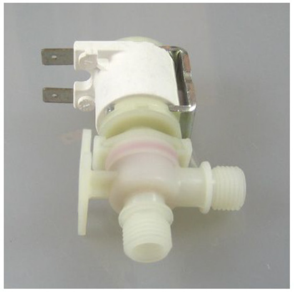
Design

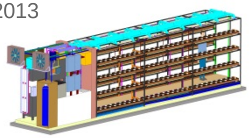
Plant Compartment

Irrigation of Grow Channels

80 mm x 160 mm x 3000 mm

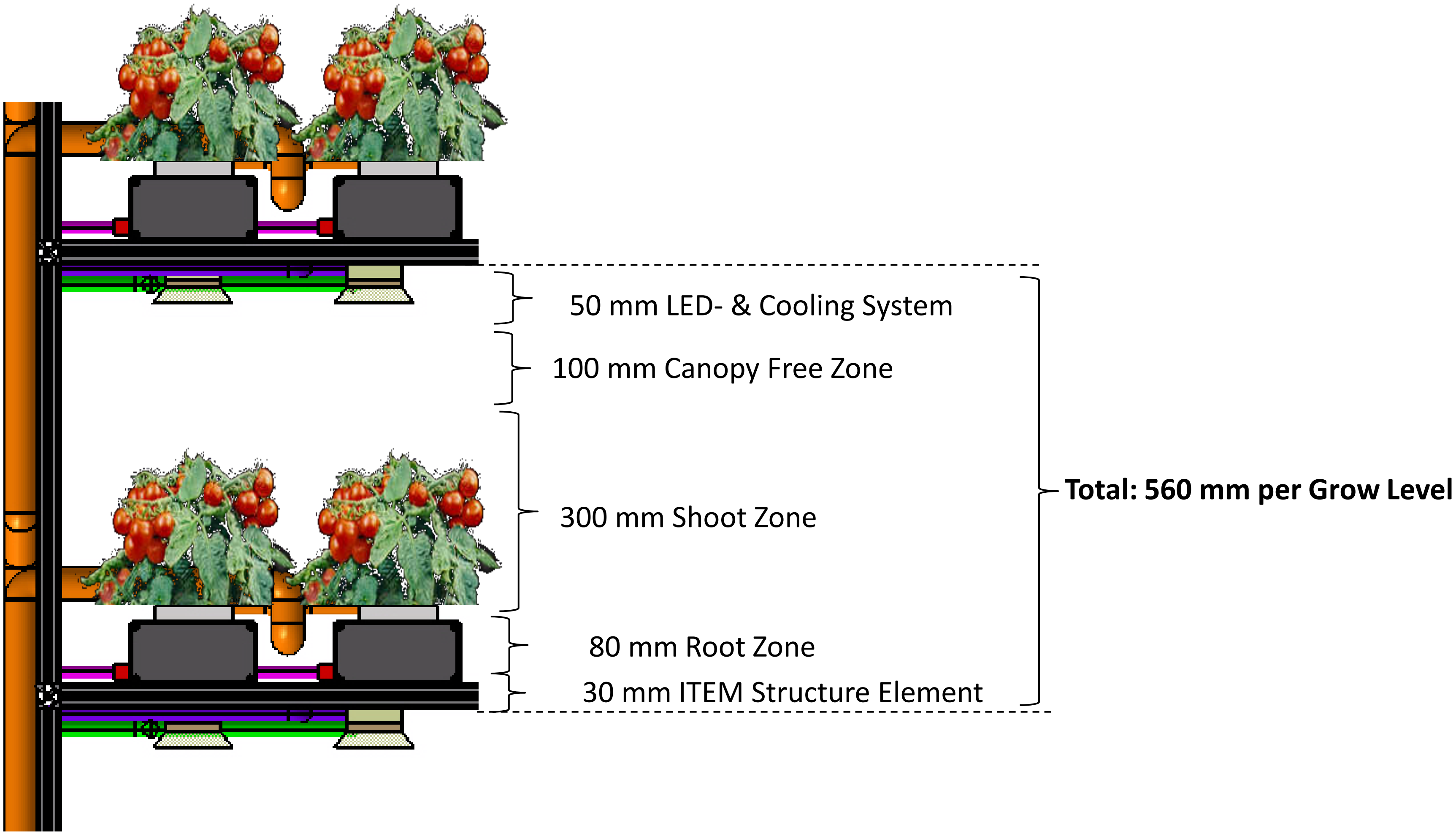






Design

Plant Compartment



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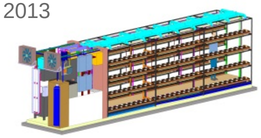
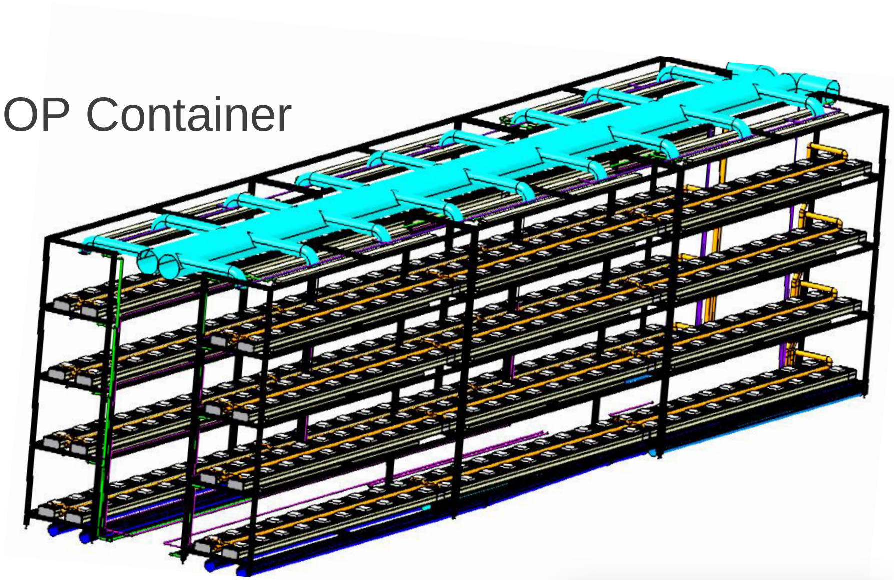


Design

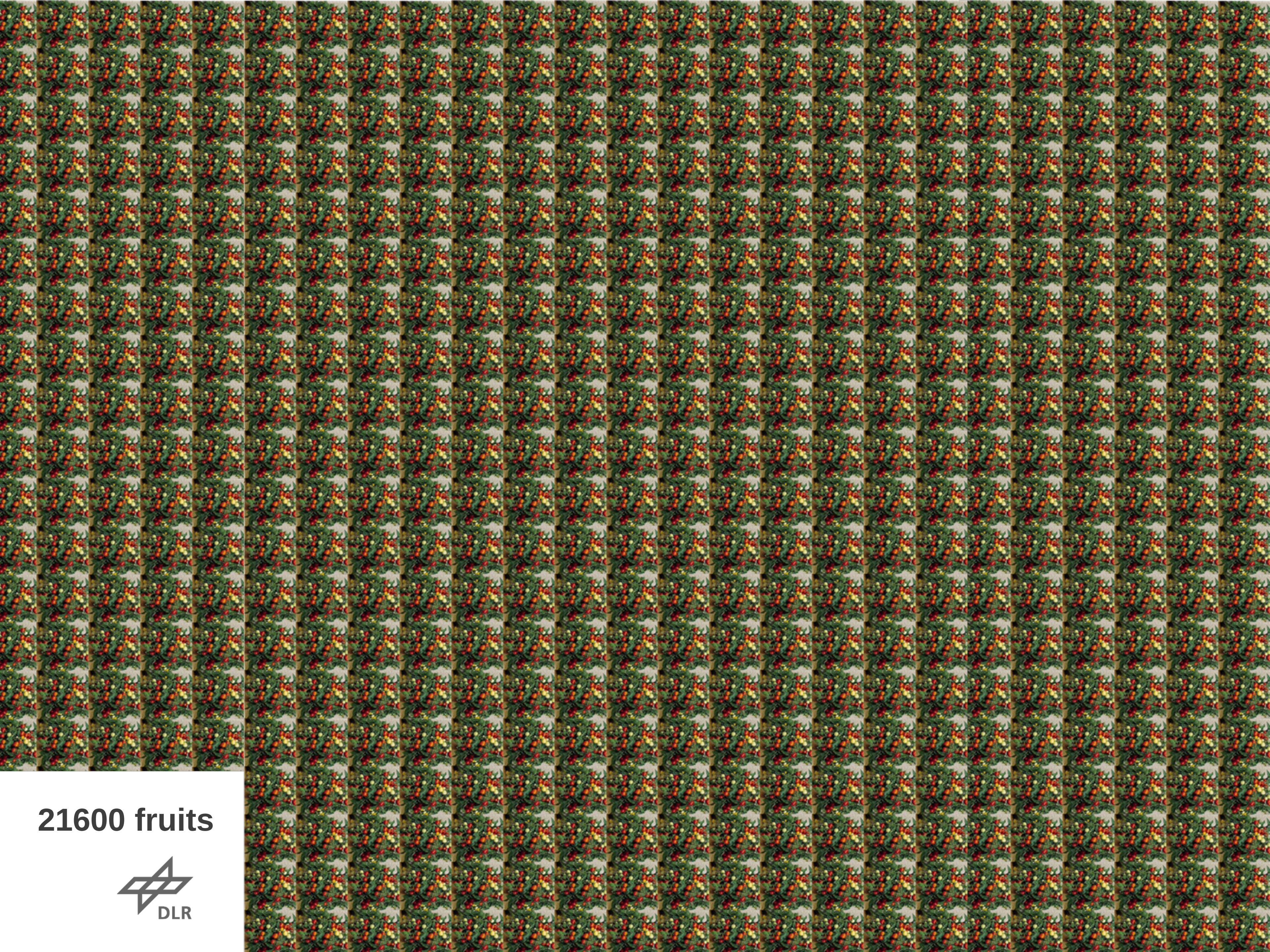
Plant Compartment

⇒ 1 x CROP Container
⇒ 2 x Plant Rows (left & right) / CROP Container
⇒ 4 x Levels / Plant Row
⇒ 3 x Segments / Plant Row
⇒ 2 x Grow Channels / Segment
⇒ 10 x Micro-Tina / Grow Channel

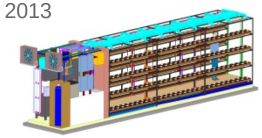


=> 43 m^2 Total Grow Area

1 x 2 x 4 x 3 x 2 x 10 = 480 Mirco-Tina plants

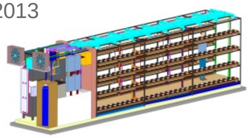


21600 fruits



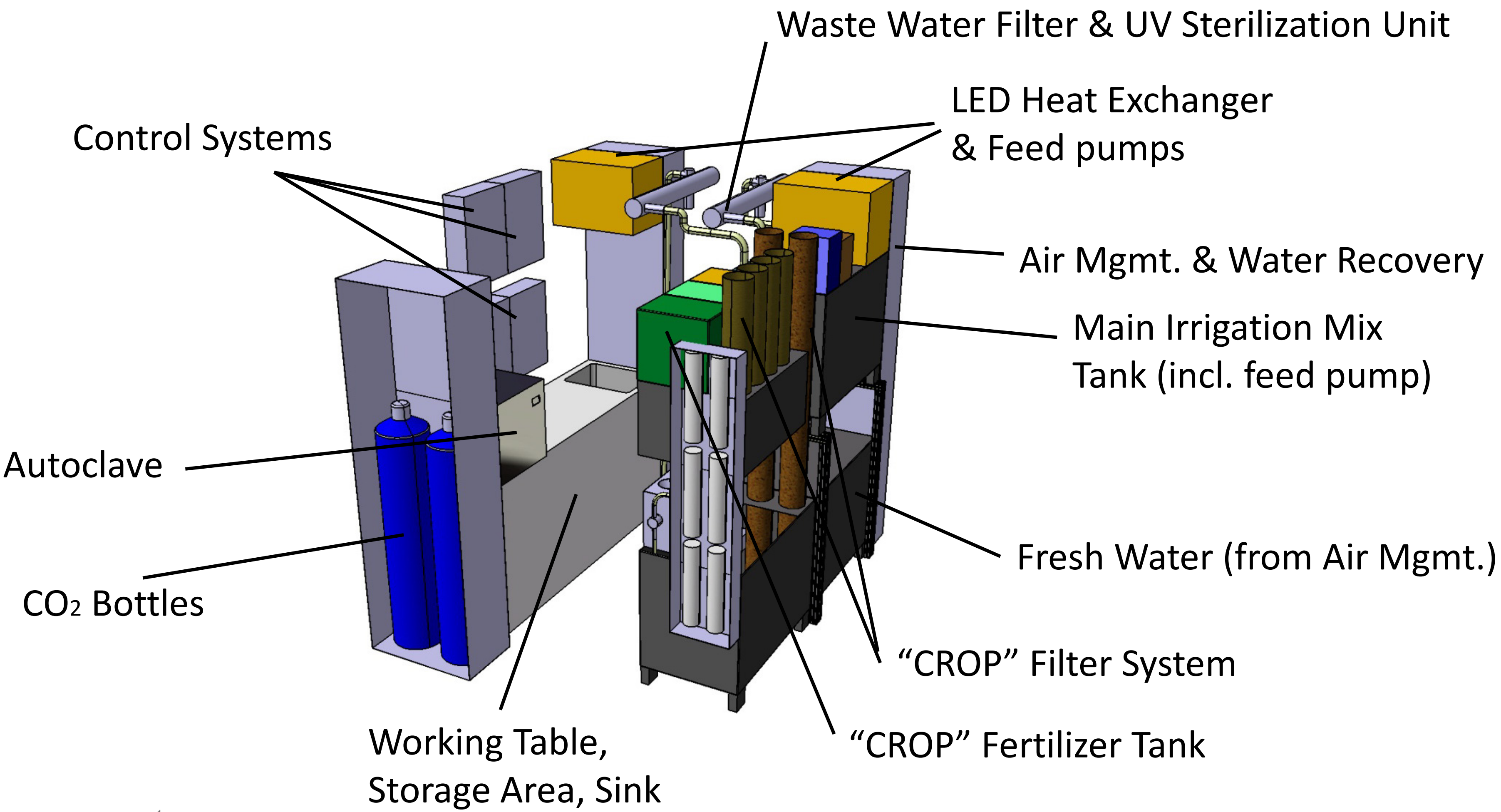
Design

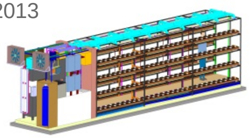
	Tomato "Micro Tina"	White Cabbage "Kalorama"
Growth period	91 days	100 days
Space demand	30 x 30 x 30 cm^3	30 x 30 x 30 cm^3
Amount of plants	480	480
Crop per day	1858 g	15034 g
N-demand per day	1,858 g	30,067 g
NO_3-demand per day	8,122 g	133,155 g
Urea demand per day	3,931 g	64,494 g
Urine demand per day (15 g Urea/l)	0,3 l	4,3 l



Design

Service Compartment



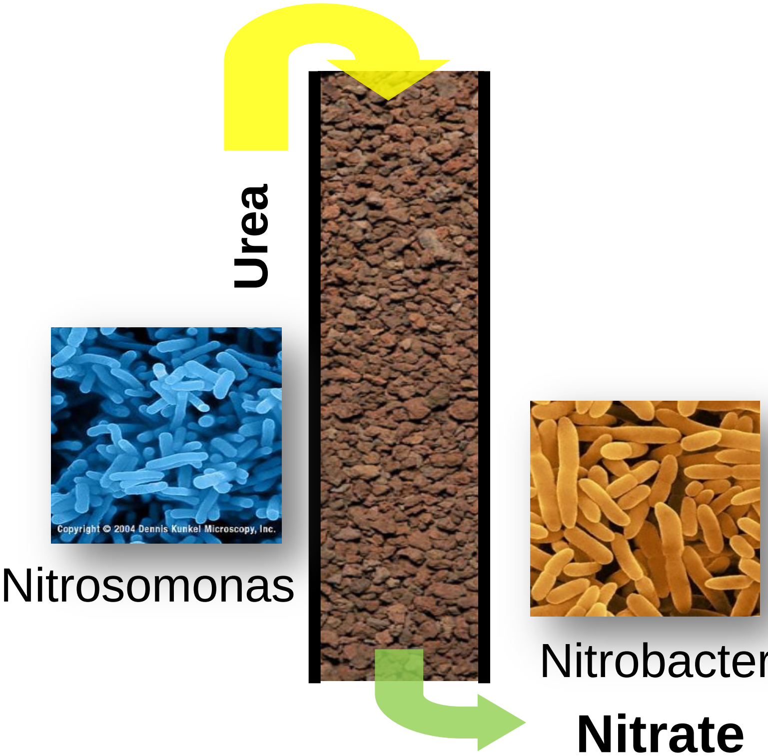


Filter Design

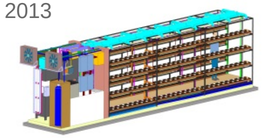
Service Compartment

„C.R.O.P." * biofilter:

- Microbiologic habitat
- Small anaerobic zones
- Dynamic adaption to nutrition source
- Cultivation of synergetic microorganisms
- Low energy demand (only pump power)
- can handle micro pollutants
- Restart capability
- Oxidative decontamination



***Combined Regenerative Organic-Food Production**



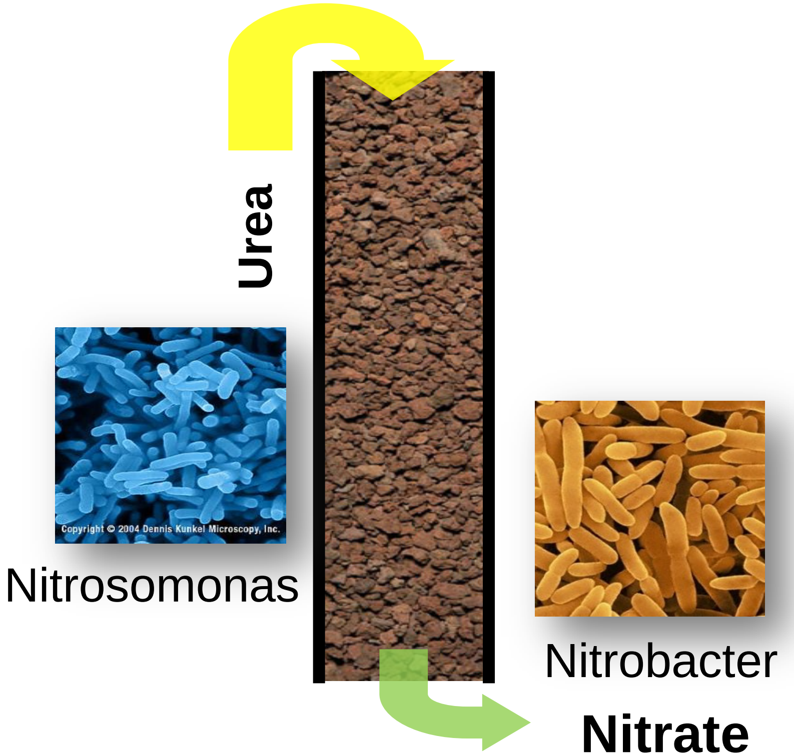
Filter Design

Service Compartment

Urea → Ammonia → Nitrite → Nitrate

(Carbon / Fat → $CO_{2)}$

→



Filtration performance
(solution with 21% urine + 6l lava): 2,8 g/day nitrate

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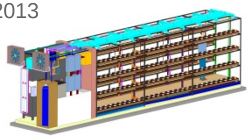
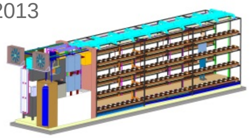


Filter Design

Service Compartment

- **<u>Works also for shredded bio-waste (white cabbage):</u>**

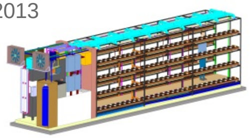
DLR



ECS Design

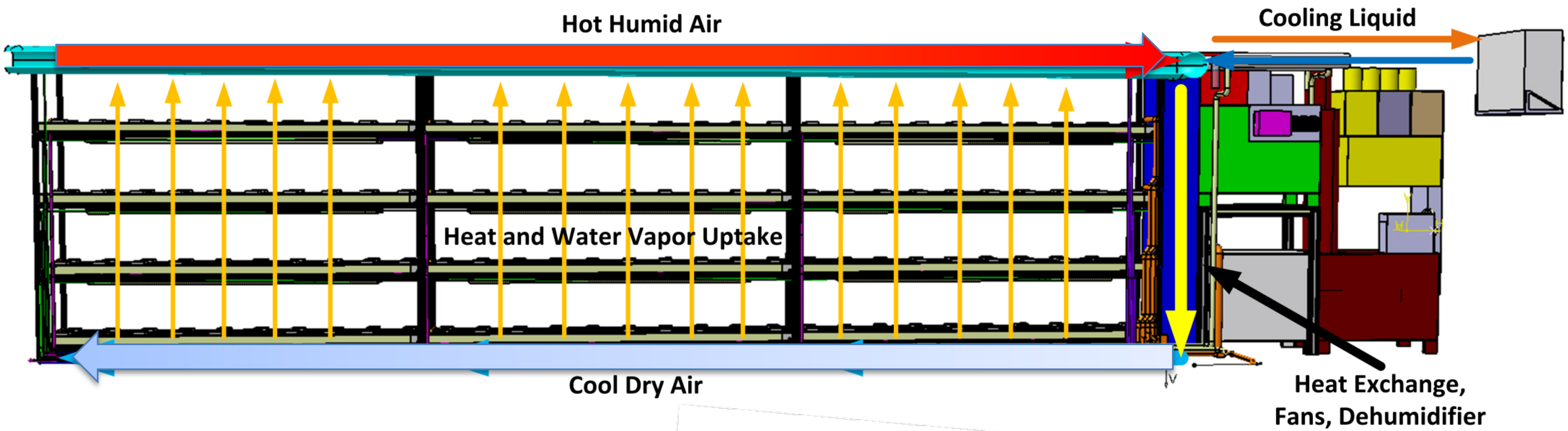
Service Compartment

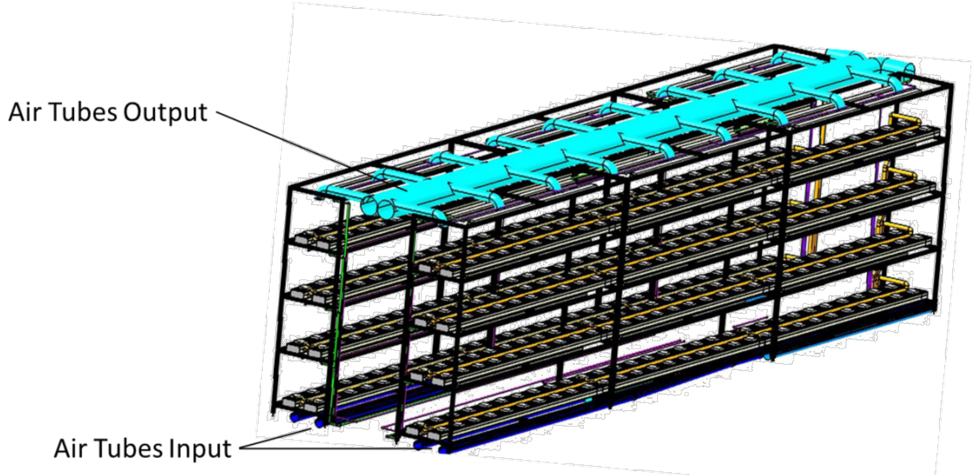
ECS Subsystem	Requirement	Value
Ventilation		
Air exchange	minimum	1 chamber volume per minute
Air mixing	high	-
Air speed	maximum in plant compartment	0.5 – 1.0 m/s
CO_2 provision		
CO_2 partial pressure	-	400 – 800 ppm
CO_2 supply rate	for the whole container	18.5 l/(m²*d) (gasous)
Humidity control		
Relative Humidity (RH)	maximum	70 %
Transpiration rate	for the whole container	350 – 500 l/d
Thermal control		
Temperature	between	17 – 25 °C
Heat production	mainly LED panels	11.5 – 15.3 kW

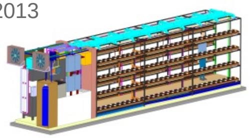


ECS Design

Service Compartment







Light Design

Service Compartment

- **Trade between:**

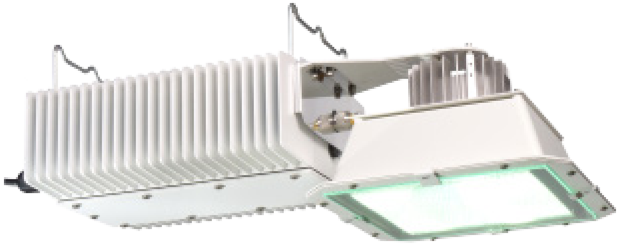
LED

-specific spectra

-UV possible

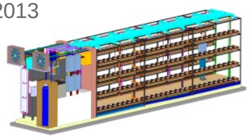
-better for space flight

LEP (Plasma)



-continuous spectrum

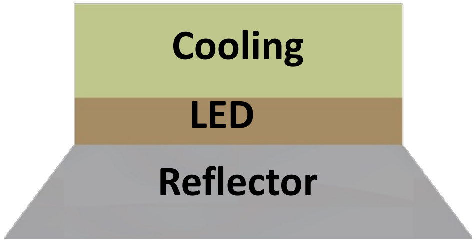
-no UV

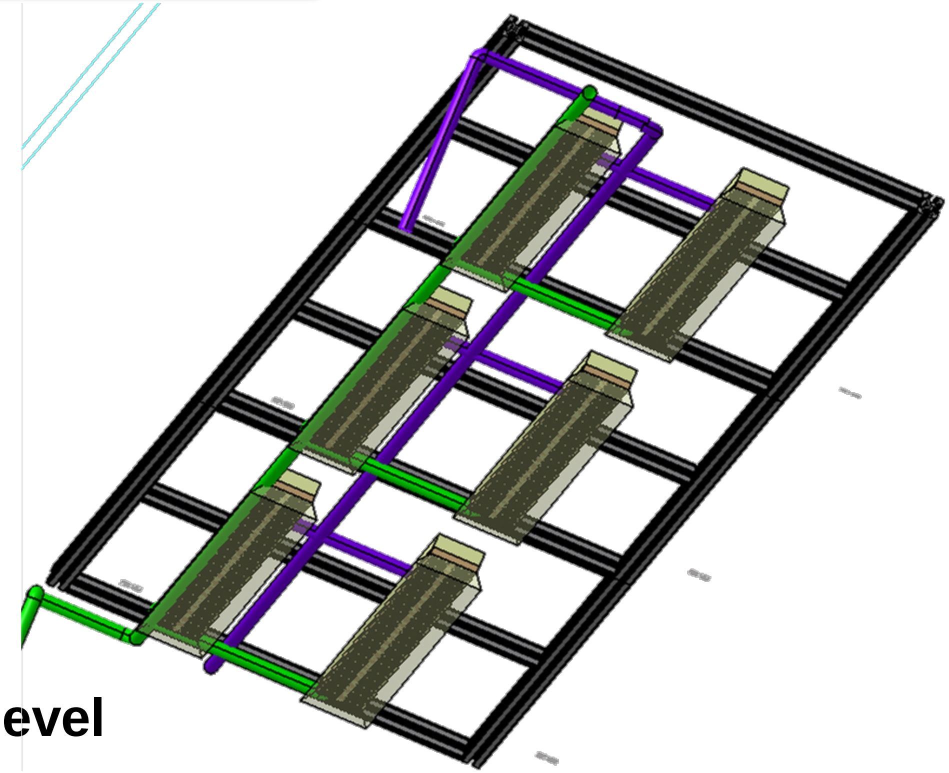


Light Design

Service Compartment

- **<u>LED design:</u>**

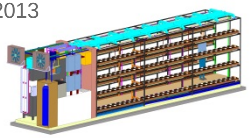




1 LED bar per 3m

6 LED bar per plant row and level

<u>Total</u>: 48 LED bars

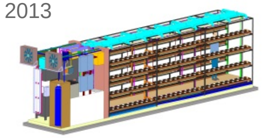


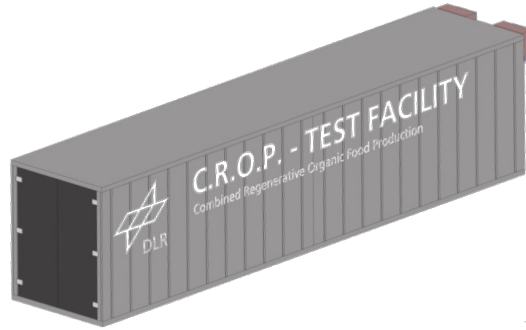
Power Design

Service Compartment

Elements	Total Power with Margin [kW]	Total Energy Consumption with Margin [kWh]
Aerobic Composter	1,25	1,31
Light	19,08	267,12
Air, CO_2, Thermal	5,23	125,52
Measurement, Controlling, Power	1,79	37,68
Plant Compartment	0,00	0,00
Structure	0,00	0,00
Total	27,35	431,63

DLR



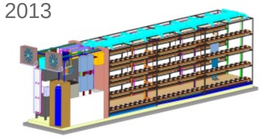


Outlook

EDEN Research Team:

- 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)
- Development of Controlled Environment Agriculture (CEA) Technologies
- EDEN Group:
  - 3 x Staff Members
  - 1 x Post doc (Marie Curie)
  - 1 x PhD Candidate (ESA NPI)
  - up to 5 students

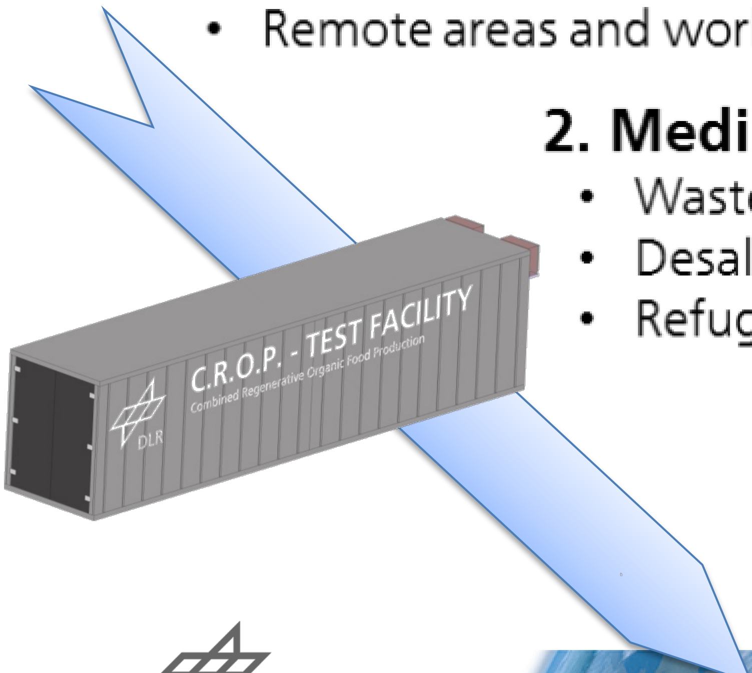
DLR Institute of Space Systems



Outlook

1. Small-scale Remote Markets

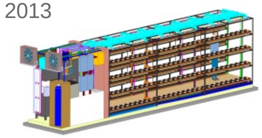
- Antarctic/Arctic research stations,
- Very large offshore structures,
- Research vessels/oil tankers,
- Remote military camps,
- Remote summit camps,
- Remote areas and work sites.



2. Medium-scale Specialized Markets

- Waste water treatment plants
- Desalination chambers &
- Refugee camps

DLR



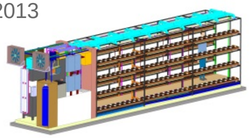
Outlook

3. Large-scale *Vertical Farming* Markets

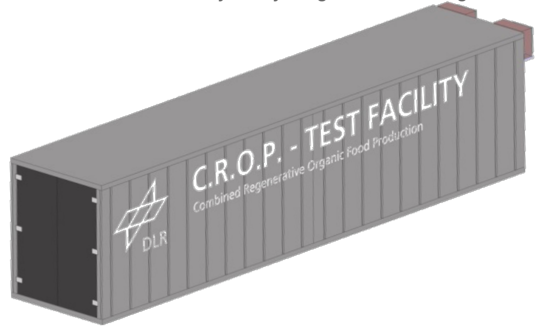
- Mega cities,
- Abandoned buildings
- Taiga regions
- Desert countries.

4. Medium-scale Research Oriented Markets

- Plant research,
- Pharmaceutical- &
- Seed companies
- Molecular farming

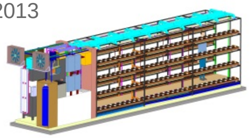


Outlook



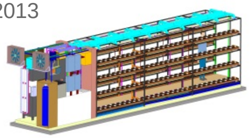
5. Micro-scale Commercial Markets

- Home farming,
- Camping caravans,
- Recreational boats,
- Nursing homes,
- Prisons,
- Schools,
- Restaurants/hotels and
- Submarines/bunkers

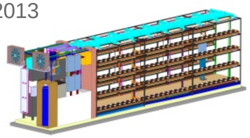


Thanks to the study team…

…and you for your Friday attention!



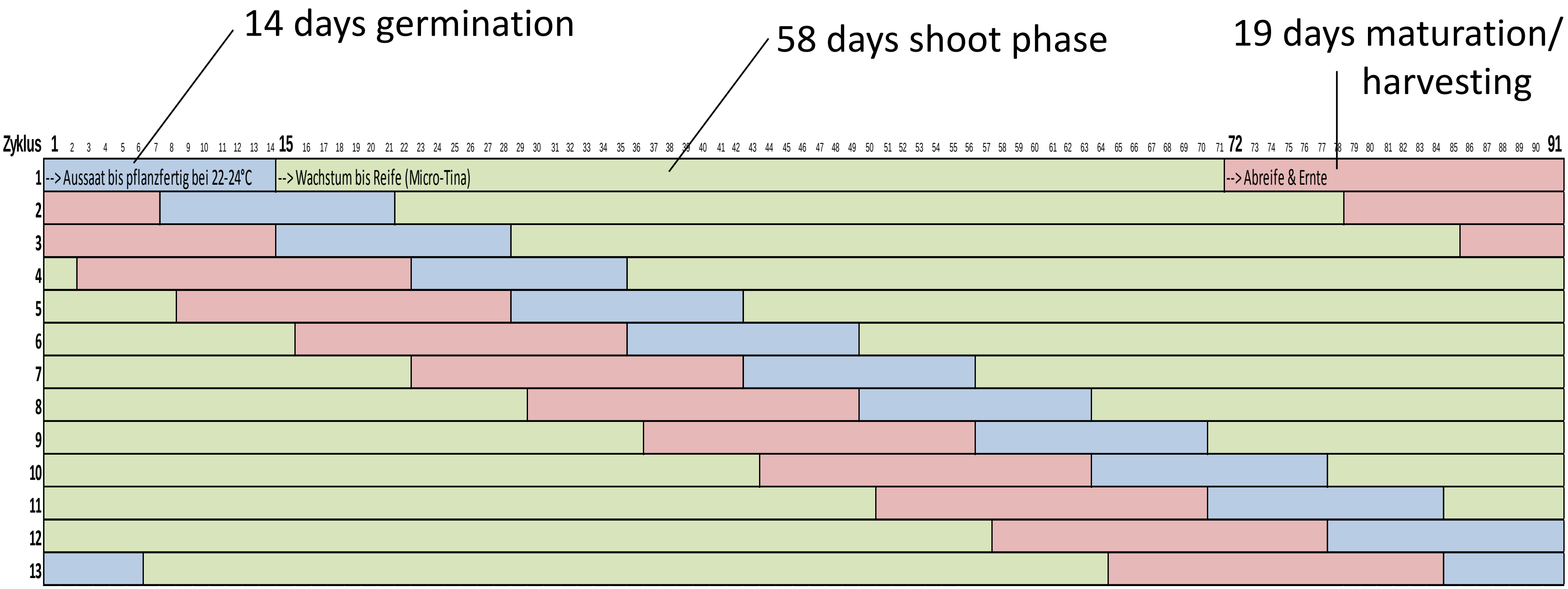
Backup Slides:

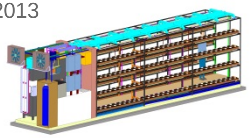


Design

Plant Compartment

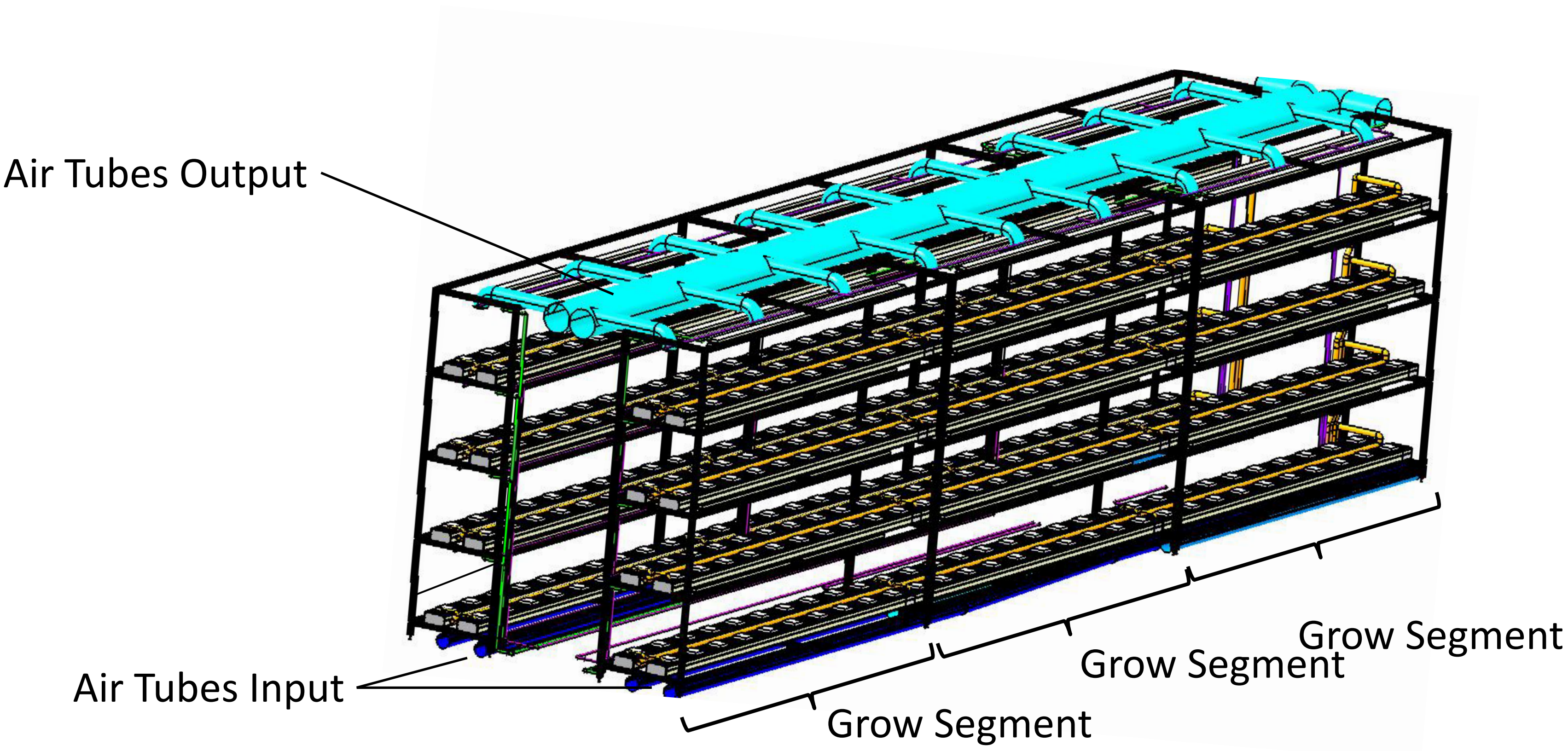
- **Plant Cycle:**





Design

Plant Compartment



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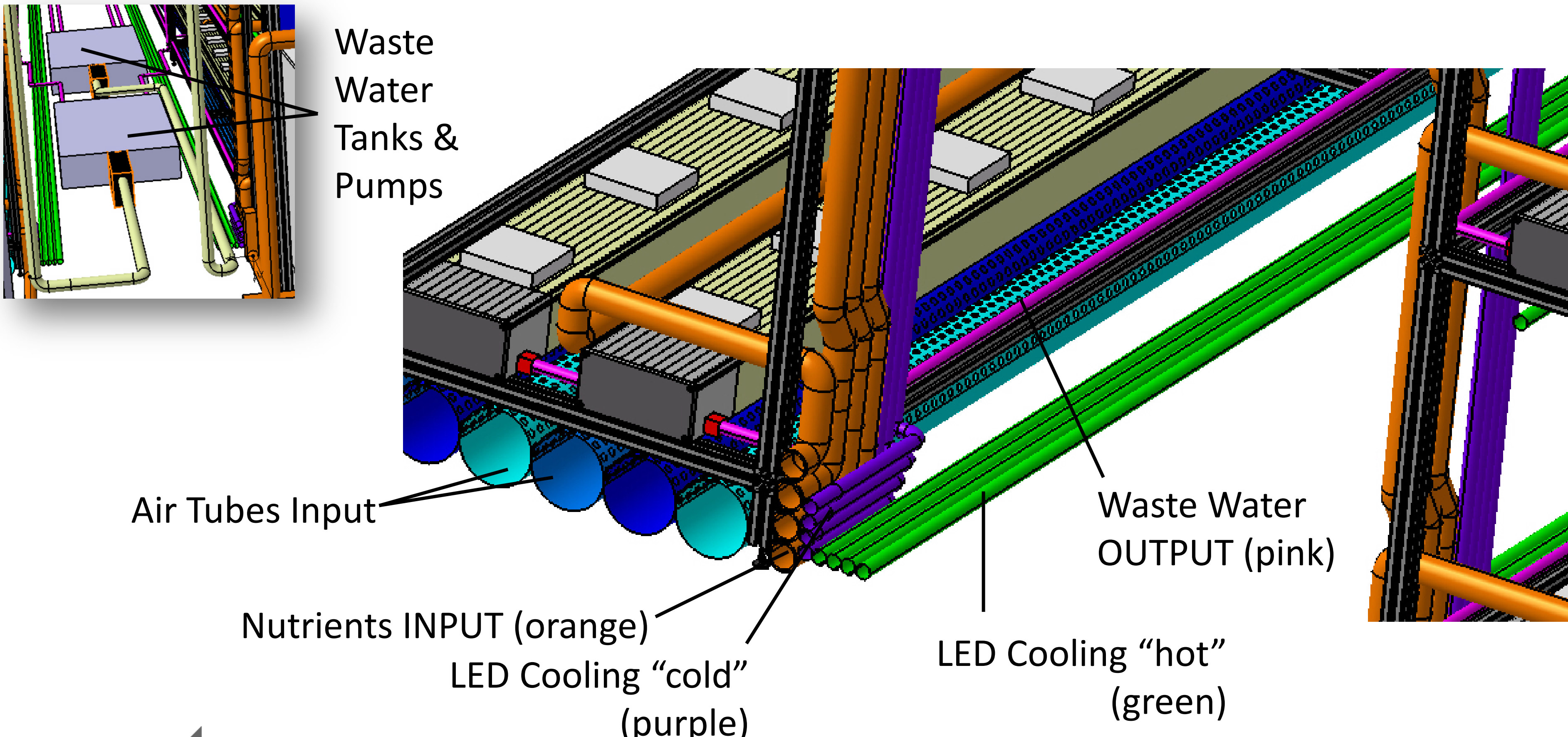
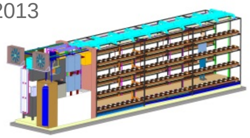
Design

Plant Compartment



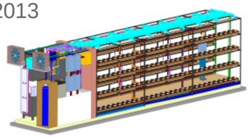


Design

Plant Compartment

- **per week/harvest:**

	40 Plants Micro Tina	40 Plants White Cabbage	1 Plant Micro Tina	1 Plant White Cabbage
Amount of crop	1800 pieces	40 pieces	45 pieces	1 piece
Wet mass of crops	12,42 kg	116,00 kg	0,31 kg	2,90 kg
Nitrogen consumption	12,42 g	232,00 g	0,31 g	5,80 g
Nitrate demand	55,00 g	1027,43 g	1,38 g	25,69 g
Urea demand	26,64 g	497,64 g	0,67 g	12,44 g
Urine demand	1,77 l	33,18 l	0,04 l	0,83 l

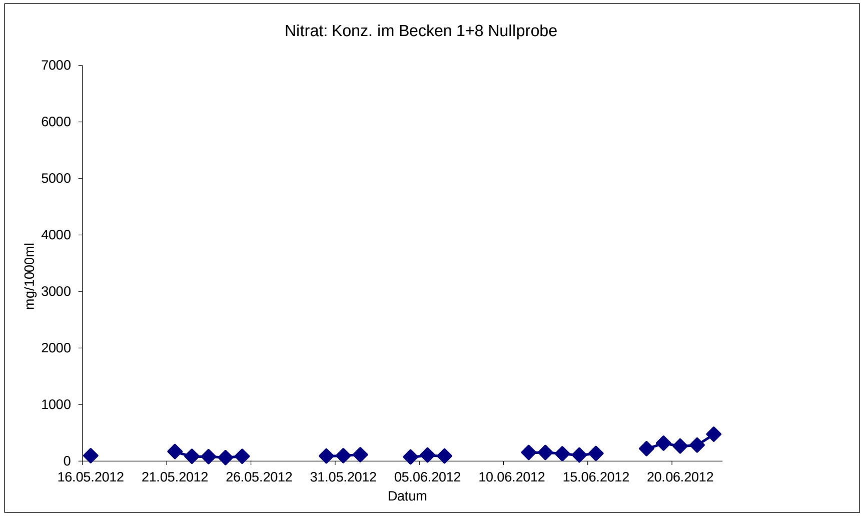


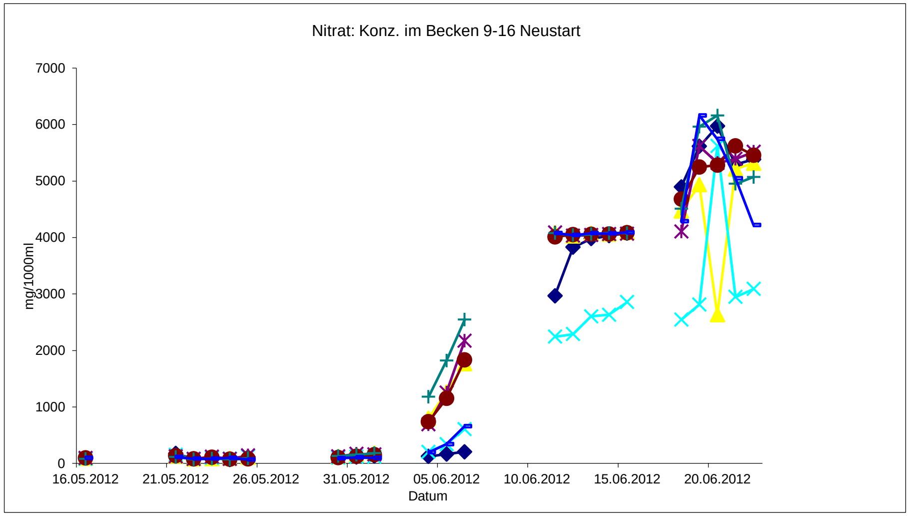
Design

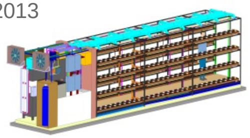
Service Compartment

Bacterial titer (aerob):
22° 1,00E+09/ml
36° 9,00E+06/ml
6.6% syn. Urine

Bacterial titer (aerob):
22° 4,86E+02/ml
36° 3,28E+02/ml
6.6% syn. Urine







Light Design

Service Compartment

- Light output: **500 µmol/m²/s** at the top of the plant during 16 hours
- During 77 days: plants between **5 and 20 cm** height
- Light spectrum: include **UVA 315 - 400 nm**
- Minimum covered area at a 40 cm distance: **15 cm x 3m**

Prozess Plan