Food Production within a Container by Recycling Urine and Organic Waste


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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:

Configuration

Power

Thermal

iteration

Project Manager/Systems Engineer

Configuration

Power

Thermal

Light
Concurrent Engineering

**Concurrent Design / Engineering Process**

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

**The five key elements:**
Concurrent Engineering

CEF Positionen (C.R.O.P.-Container)

- Guest
- Plant Compartment
- Higher Plants
- Light (/Thermal)
- Air/ Envir. Control
- Aerobic Composter
- Customer
- Customer
- Moderator
- CEF
- Guest
- Malik
- Systems/ Cost
- Budgets/ Nutrient Flow
- Measurement, Controlling, Power
- Configuration II
- Configuration I
- Guest
- Guest
- Guest
- Guest
- Guest
- Guest
Concurrent Engineering
Design

40' High Cube Container

9 m Length

2.15 m width

2.49 m Height

Plant Compartment

Service Compartment

www.DLR.de • Chart 9 • D. Quantius • Food Production within a Container by Recycling Urine and Organic Waste • 64. IAC, Beijing, China • 2013
### Options:
- **Aeroponic** *(no!)*
- **Deep water** *(no!)*
- **NFT** *(no!)*
- **Flooding** *(optional)*
- **Continuous flow** *(yes!)*
- **Drip irrigation** *(optional)*

### Design

**Plant Compartment**

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Considered Irrigation System/s</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA Steckler UA-CEAC Lunar Greenhouse</td>
<td>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).</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>ESA OEGEU [41]</td>
<td>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.</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Mc Murdo Greenhouse [42]</td>
<td>NFT system, with electric conductivity and pH hand-adjusted. Perlite and vermiculite were used as growing media.</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>Amudsen Scott SPFGC [29]</td>
<td>Redistributing 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 m³ min⁻¹) directly in the nutrient solution storage.</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>TAS-I SEEDS Lunar FARM [35]</td>
<td>Soil discarded; considered hydroponic, aeroponic and zeoponic cultivation methods. NFT chosen for compromise between mass and needed water buffer.</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>MELISSA UAB [43]</td>
<td>Nutrient Film Technique was selected and implemented.</td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Irrigation of Grow Channels

80 mm x 160 mm x 3000 mm

Plant Compartment

Input

Cage holders

Removable grow lid

Design

Plant Compartment

Output
Design

Plant Compartment

- 50 mm LED- & Cooling System
- 100 mm Canopy Free Zone
- 300 mm Shoot Zone
- 80 mm Root Zone
- 30 mm ITEM Structure Element

Total: 560 mm per Grow Level
Design

- 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 m² Total Grow Area

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

1 x 2 x 4 x 3 x 2 x 10 = 480 Micro-Tina plants
⇒ 43 m² Total Grow Area

21600 fruits
## Design

<table>
<thead>
<tr>
<th></th>
<th>Tomato &quot;Micro Tina&quot;</th>
<th>White Cabbage &quot;Kalorama&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth period</strong></td>
<td>91 days</td>
<td>100 days</td>
</tr>
<tr>
<td><strong>Space demand</strong></td>
<td>30 x 30 x 30 cm³</td>
<td>30 x 30 x 30 cm³</td>
</tr>
<tr>
<td><strong>Amount of plants</strong></td>
<td>480</td>
<td>480</td>
</tr>
<tr>
<td><strong>Crop per day</strong></td>
<td>1858 g</td>
<td>15034 g</td>
</tr>
<tr>
<td><strong>N-demand per day</strong></td>
<td>1,858 g</td>
<td>30,067 g</td>
</tr>
<tr>
<td><strong>NO₃-demand per day</strong></td>
<td>8,122 g</td>
<td>133,155 g</td>
</tr>
<tr>
<td><strong>Urea demand per day</strong></td>
<td>3,931 g</td>
<td>64,494 g</td>
</tr>
<tr>
<td><strong>Urine demand per day</strong></td>
<td>0,3 l</td>
<td>4,3 l</td>
</tr>
<tr>
<td></td>
<td>(15 g Urea/l)</td>
<td></td>
</tr>
</tbody>
</table>
Design

Service Compartment

- Waste Water Filter & UV Sterilization Unit
- LED Heat Exchanger & Feed pumps
- Air Mgmt. & Water Recovery
- Main Irrigation Mix Tank (incl. feed pump)
- Fresh Water (from Air Mgmt.)
- “CROP” Filter System
- “CROP” Fertilizer Tank
- Working Table, Storage Area, Sink
- Autoclave
- CO₂ Bottles
- Control Systems
Filter Design

„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 → CO₂)

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

Service Compartment

- Works also for shredded bio-waste (white cabbage):
## ECS Design

### Service Compartment

<table>
<thead>
<tr>
<th>ECS Subsystem</th>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ventilation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air exchange</td>
<td>minimum</td>
<td>1 chamber volume per minute</td>
</tr>
<tr>
<td>Air mixing</td>
<td>high</td>
<td>-</td>
</tr>
<tr>
<td>Air speed</td>
<td>maximum in plant compartment</td>
<td>0.5 – 1.0 m/s</td>
</tr>
<tr>
<td><strong>CO₂ provision</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ partial pressure</td>
<td>-</td>
<td>400 – 800 ppm</td>
</tr>
<tr>
<td>CO₂ supply rate</td>
<td>for the whole container</td>
<td>18.5 l/(m²*d) (gasous)</td>
</tr>
<tr>
<td><strong>Humidity control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Humidity (RH)</td>
<td>maximum</td>
<td>70 %</td>
</tr>
<tr>
<td>Transpiration rate</td>
<td>for the whole container</td>
<td>350 – 500 l/d</td>
</tr>
<tr>
<td><strong>Thermal control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>between</td>
<td>17 – 25 °C</td>
</tr>
<tr>
<td>Heat production</td>
<td>mainly LED panels</td>
<td>11.5 – 15.3 kW</td>
</tr>
</tbody>
</table>
ECS Design

Service Compartment

Hot Humid Air

Heat and Water Vapor Uptake

Cool Dry Air

Cooling Liquid

Heat Exchange, Fans, Dehumidifier

Air Tubes Output

Air Tubes Input
Light Design

- Trade between:

  - LED
    - specific spectra
    - UV possible
    - better for space flight

  - LEP (Plasma)
    - continuous spectrum
    - no UV

Service Compartment
Light Design

- **LED design:**
  - 1 LED bar per 3m
  - 6 LED bar per plant row and level

**Total:** 48 LED bars
<table>
<thead>
<tr>
<th>Elements</th>
<th>Total Power with Margin [kW]</th>
<th>Total Energy Consumption with Margin [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic Composter</td>
<td>1,25</td>
<td>1,31</td>
</tr>
<tr>
<td>Light</td>
<td>19,08</td>
<td>267,12</td>
</tr>
<tr>
<td>Air, CO₂, Thermal</td>
<td>5,23</td>
<td>125,52</td>
</tr>
<tr>
<td>Measurement, Controlling, Power</td>
<td>1,79</td>
<td>37,68</td>
</tr>
<tr>
<td>Plant Compartment</td>
<td>0,00</td>
<td>0,00</td>
</tr>
<tr>
<td>Structure</td>
<td>0,00</td>
<td>0,00</td>
</tr>
<tr>
<td>Total</td>
<td>27,35</td>
<td>431,63</td>
</tr>
</tbody>
</table>
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
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
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:
**Plant Cycle:**

- 14 days germination
- 58 days shoot phase
- 19 days maturation/harvesting
Design

Plant Compartment

Air Tubes Output

Air Tubes Input

Grow Segment

Grow Segment

Grow Segment
Design

Plant Compartment

Waste Water Tanks & Pumps

Air Tubes Input

Nutrients INPUT (orange)

LED Cooling “cold” (purple)

Waste Water OUTPUT (pink)

LED Cooling “hot” (green)
Design

- *per week/harvest:*

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

Nitrat: Konz. im Becken 1+8 Nullprobe

Nitrat: Konz. im Becken 9-16 Neustart
Light Design

- 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**