Mars-Lunar Greenhouse (M-LGH) at the University of Arizona: Status and Path Forward

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Mars-Lunar GreenHouse (M-LGH): NASA Steckler Phase III

- M-LGH has been awarded for Phase III studies
  - European Collaborators:
    - TAS-I (Dr. Lobascio), DLR (Dr. Schubert), AeroSekur (Dr. Rossignoli), CNR (Dr. Battistelli)
- Goals and Objectives
  - **Goals:** Develop a high-fidelity, 4-units greenhouse system to test BLSS technologies for future planetary habitat. Evaluate performances in realistic prototype (biomass/food production, atmosphere and water revitalization)
  - **Objective #1:** Maximize crop production for the poly-cultivation system and evaluate the contribution to the overall caloric intake of the crew.
  - **Objective #2:** Operate the Solar Concentrator Power System (SCPS), collect data, and deliver estimates of its use as integral part of the Bioregenerative Life Support System (BLSS). Evaluate the impact of a solar collector on the overall M-LGH energy budget.
A Permanent Planetary Outpost

- Extend human presence on the surface
- Allow for *in situ* technology development and testing
- Extensive use of Bio-regenerative Life Support System (BLSS) technologies
- Concept from
  - University of Arizona
    - UA-SIE/AME
    - UA-CEAC
    - Sadler Machine Co.
Bioregenerative Life Support System for Planetary Outposts

Atmosphere and Water
Revitalization

Food Production

Composter Microbial Respiration
Human Waste
Aqueous Bioreactor
Nutrient Oxygenation
Compost Waste
Incineration
Crew Respiration
Greenhouse Oxygen
Toilet
Oxygen
Carbon Dioxide
Organics Filter
Carbon Dioxide

Galley Waste
Incinerated Waste
Beverages
Sweets
Grains
Meat
Condiments
Toilet

Food Production

Habitat Atmosphere Losses
Food Production
Atmosphere and Water
Revitalization
Mars-Lunar Greenhouse Prototype: UA Testbed

Monitored Input and Output to the Lunar Greenhouse

Input: energy, water, nutrients, CO2, labor
Output: oxygen, water, biomass
Mars-Lunar Greenhouse Prototype: Key Components

- Monitoring and Control System
- Hydroponic Cable Culture System
M-LGH Performances

Carbon Balance

<table>
<thead>
<tr>
<th>Interval</th>
<th>CO₂ Treatment</th>
<th>CO₂ Leakage kg</th>
<th>C₂O₂ + CO₂ kg</th>
<th>CO₂ Injection kg</th>
<th>Carbon Balance % Difference</th>
<th>Daily CO₂ In kg per Biomass Gain</th>
<th>Biomass Production kg d⁻¹</th>
<th>CO₂ kg d⁻¹</th>
<th>CO₂ kg m⁻² d⁻¹</th>
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Water Balance

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<tr>
<th>Interval</th>
<th>CO₂ Treatment</th>
<th>Replenishment (+/-)</th>
<th>Condensate (+/-)</th>
<th>Biomass (+/-)</th>
<th>Vapor Leak (+/-)</th>
<th>% Difference</th>
<th>Daily Condensate per Biomass Gain kg kg⁻² d⁻¹</th>
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</thead>
<tbody>
<tr>
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<td>38.6</td>
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Energy Balance

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<th>Inputs</th>
<th>kWh</th>
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<td>Q_air heat</td>
<td>66.0 ± 2.1</td>
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<td>Q_lamp light</td>
<td>37.7</td>
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<td>Q_air cool</td>
<td>67.9 ± 1.3</td>
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<tr>
<td>Q_condensate</td>
<td>34.3 ± 17.3</td>
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<tr>
<td>Q_solar</td>
<td>0.6 ± 0.1</td>
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<tr>
<td>Q_rad</td>
<td>0.003 ± 0.001</td>
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</table>

<table>
<thead>
<tr>
<th>Outputs</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q_lamp cool</td>
<td>42.8</td>
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<tr>
<td>Q_stay cool</td>
<td>2.5 ± NA</td>
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<tr>
<td>Q_total</td>
<td>148.1 ± 18.6</td>
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</table>

General System Performances

<table>
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<tr>
<th>Daily Average</th>
<th>Phase II</th>
<th>Phase I</th>
<th>Phase I</th>
<th>kg m⁻² d⁻¹</th>
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<tbody>
<tr>
<td>Biomass increase</td>
<td>0.06 ± 0.04</td>
<td>0.06 ± 0.01</td>
<td>kg m⁻² d⁻¹</td>
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<tr>
<td>Water production</td>
<td>22.4 ± 7.7</td>
<td>21.4 ± 1.9</td>
<td>kg d⁻¹</td>
<td></td>
</tr>
<tr>
<td>Water consumption</td>
<td>26.4 ± 8.6</td>
<td>25.7 ± 1.10</td>
<td>kg d⁻¹</td>
<td></td>
</tr>
<tr>
<td>CO₂ consumption</td>
<td>0.23 ± 0.16</td>
<td>0.22</td>
<td>kg d⁻¹</td>
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</table>
M-LGH LED-based System

- High Pressure Sodium Lamp have been replaced with a LED system provided by Phillips
- Lettuce grown under the LED modules achieved up to **54 grams/kWh** (0.0185 kWh/g) of fresh weight, edible lettuce compared to lettuce grown under a high pressure sodium system which achieved only **24 grams/kWh** (0.0417 kWh/g) of fresh weight, edible lettuce.
- Estimated 44% of energy saves
- New generation of water-cooled LED system is under development
Fresnel-based Solar Concentration Power System

- Capacity to support seven concentrators
- Two stepper motors to control altitude and azimuth
  - Control program uses date and time and output from a system of photovoltaic detectors
- Each use a Fresnel lens to focus the light
  - Focal point separation
Tuning and Transmission

- Each concentrator has its own fiber optic cable
- Tuning accomplished by maximizing output PAR
  - Adjust three degrees of freedom
- 30 meter fused silica fiber optic cables
- Inside PAR sensor was 11.4 cm from end of cable
SPSC Data Collection

- Collected Data
  - PAR before focusing (Outside PAR)
  - PAR after transmission (Inside PAR)
  - Time of Day

- PAR readings averaged over 5 minutes
- Data collection went from sunrise to sunset
- Even a single cloud pass would give a non-ideal day of data
Data Analysis and Efficiency Determination

- Inside PAR values are not as smooth due to the steps of the motors
- A simple division of the Inside PAR by the Outside PAR gives the efficiency
- Highest happens between 10:30 and 14:30 and varies between 25% and 30%
SCPS and Algae Battery for Enhanced Oxygen Production:

Figure 1: Proposed Algae-based Biological Atmosphere Revitalization System (BARS, A) and the Fresnel-based fiber optics solar concentrator (or Solar Concentrator Power System SCPS, B). BARS is based on an “algae battery” concept. SCPS is based on the existing Himawari technology.
BLSS in Deep Space Habitat: Biosphere 2

- Goal: Construct a prototype of Deep Space Habitat inside the West Lung of the Biosphere 2
  - Model around existing deep space architectures
Deep Space Habitat in the B2 Lung
Central Hub Module

- Central Hub is conceived as a two-story structure
  - Upper floor used for storage
Bio-Recycle Module

- Module includes composter and water bladder
Conclusions

• M-LGH has been funded from NASA Steckler Program for Phase III

• Enable continuing the development of a 4-units testbed for BLSS in Planetary Outposts

• Future development
  – Deep Space Habitat in Biosphere
  – Initial discussion with Hi-SEAS to include the BLSS component in their architecture