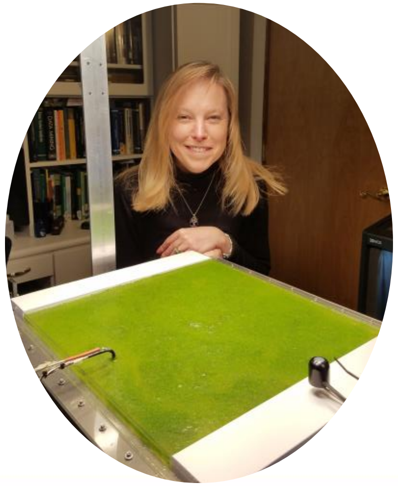
MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

2022 MELISSA CONFERENCE
8-9-10 NOVEMBER 2022

CREATING A CIRCULAR **FUTURE**

Duckweed Production for Space Life Support.

Christine Escobar, Space Lab Technologies



Habitation Systems **Space Systems** **Space Science** **Engineering Services**

It's a long way to Mars....

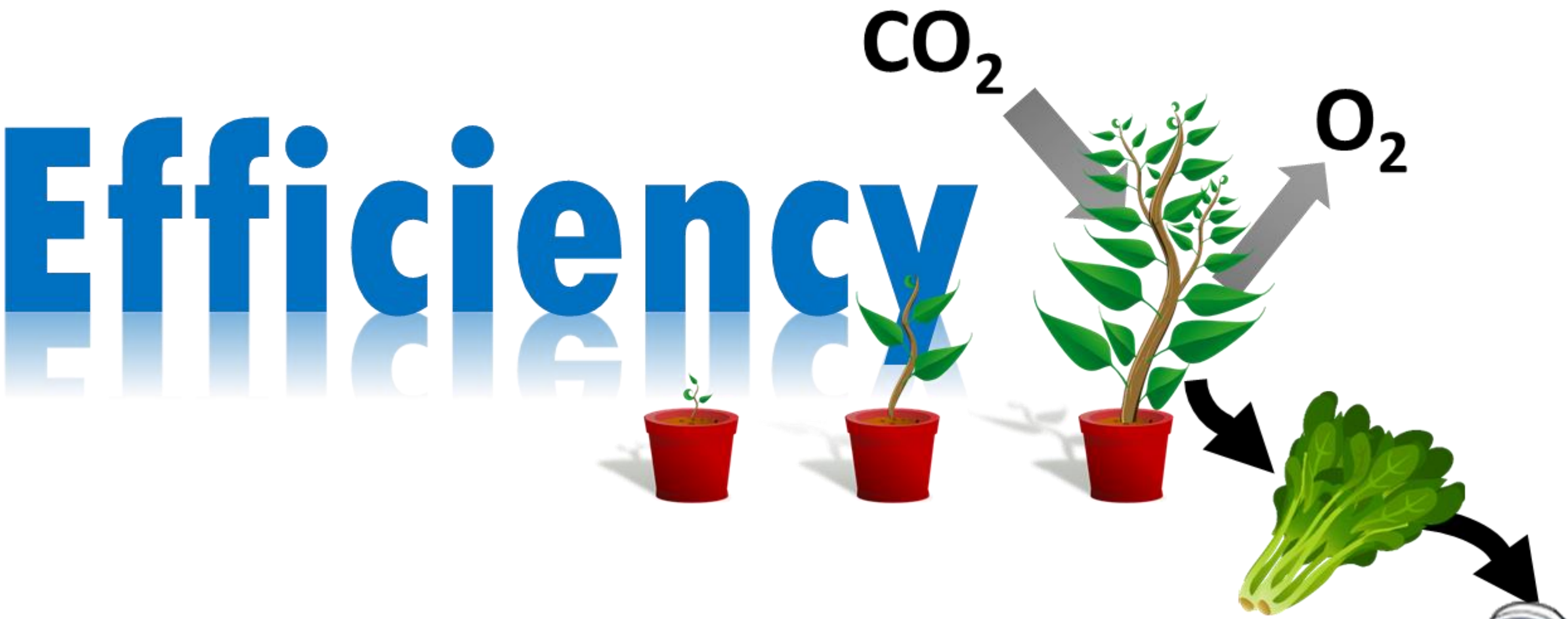
Stabilized Packaged Food for Space Missions *(www.nasa.gov)*

Regenerative Food Production for Long Duration Space Habitation

Challenges of Growing Plants in Space

- Micro-Reduced Gravity (Fluid Movement)
- Radiation
- Mass/Volume/Power Limits
- Limited Crew Time
- Reduced Pressure
- High CO2
- Dust
- Buffering Capacity
- Pathogens & Biofouling
- Quality Control/Optimization
- Waste Disposal/Processing

What Makes a Good Space Crop?



- CO_2 Consumption
- Growth Rate
- Harvest Index
- Nutritional Density
- Palatability

- Infrastructure Mass
- Water Use
- Labor (Crew Time)
- Energy Use
- Volume

✓ **ROBUST** to environmental perturbation (temp, pH, light, µG)

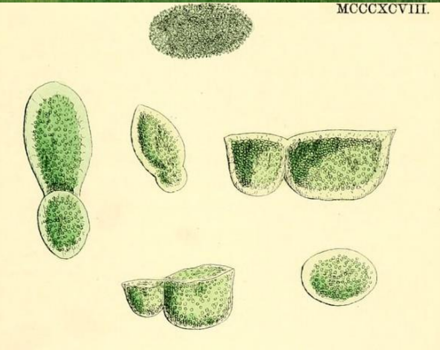
Building Better Space Crops

Genetically Modified Organisms (GMOs)

Building Better Space Crops

Environmentally Modified Organisms (EMOs)

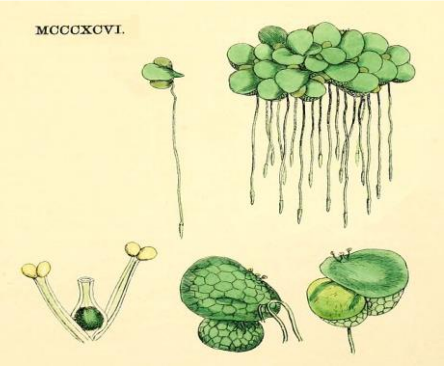


What is Duckweed?

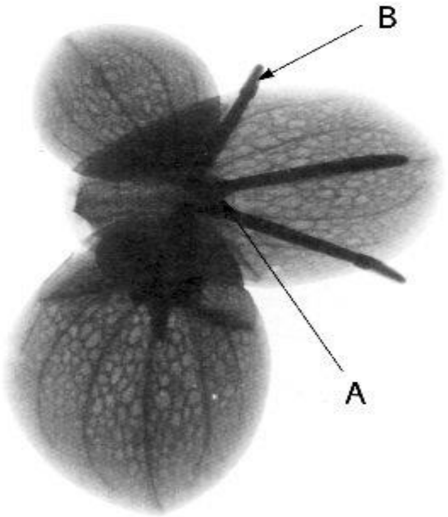
- Smallest flowering plants on Earth
- Among fastest growing in world
- Family *Lemnaceae*
- 5 genera, 37 species
- Free floating or submerged
- Still/slow flowing fresh water
- Common in lakes, ponds, canals, rice fields, ditches, and even mud

Doubles biomass 1 to 3 days!





Duckweed Anatomy



Vegetative Budding

Permanently Open (Inactive) Stomata

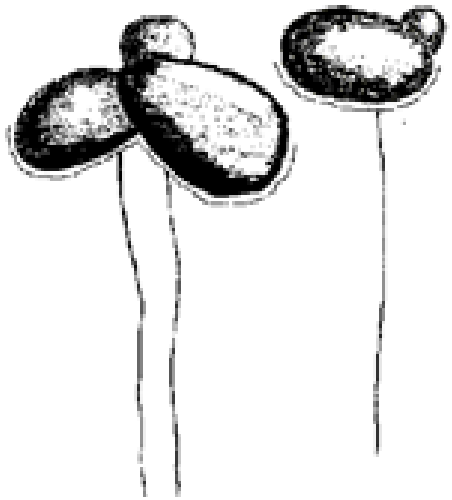
Cutin (waxy, water repellant layer) ➔ Macro-surfactant?

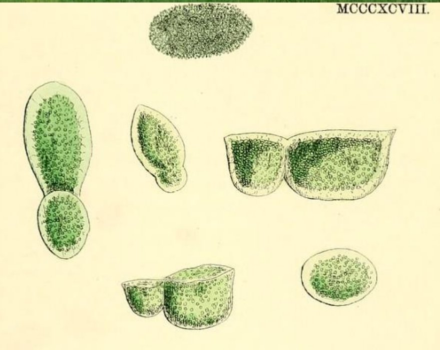
Little Structural Tissue

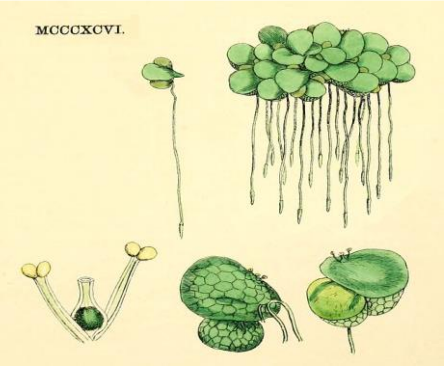
All Surfaces Absorb Nutrients & Gases

Photosynthetic Roots:

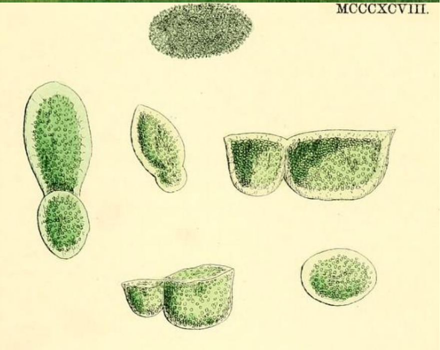
- **Mechanical stability**
- **Not always present**



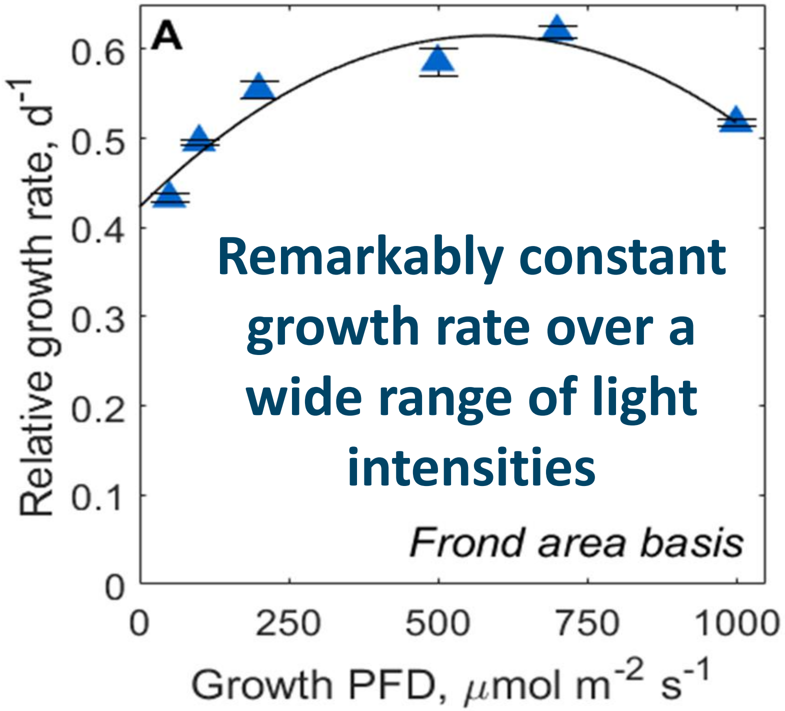


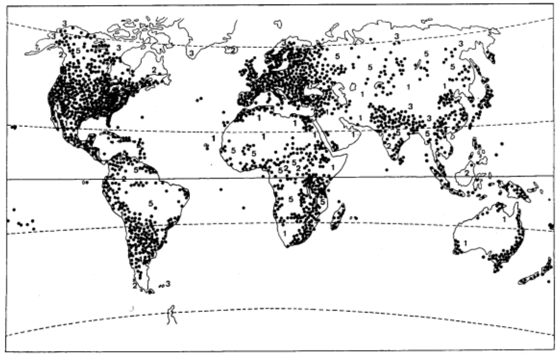




Environmental Robustness



Temperature: 6-33C

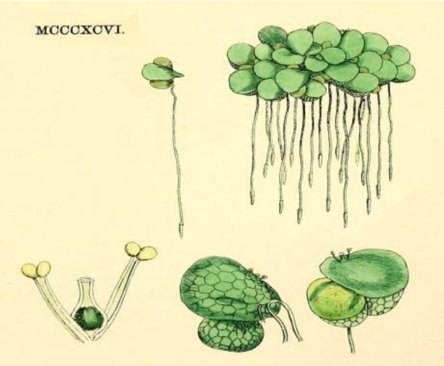
Salinity: Fresh-Brackish

pH: 3-10

O2: 0% - 100%

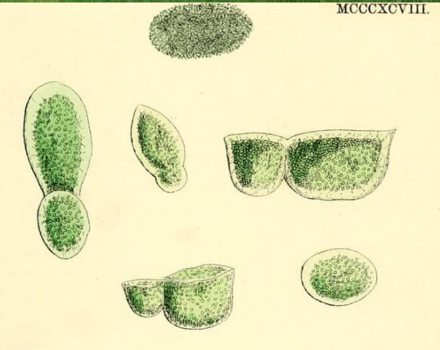
Photoperiod: 0-24 Hours

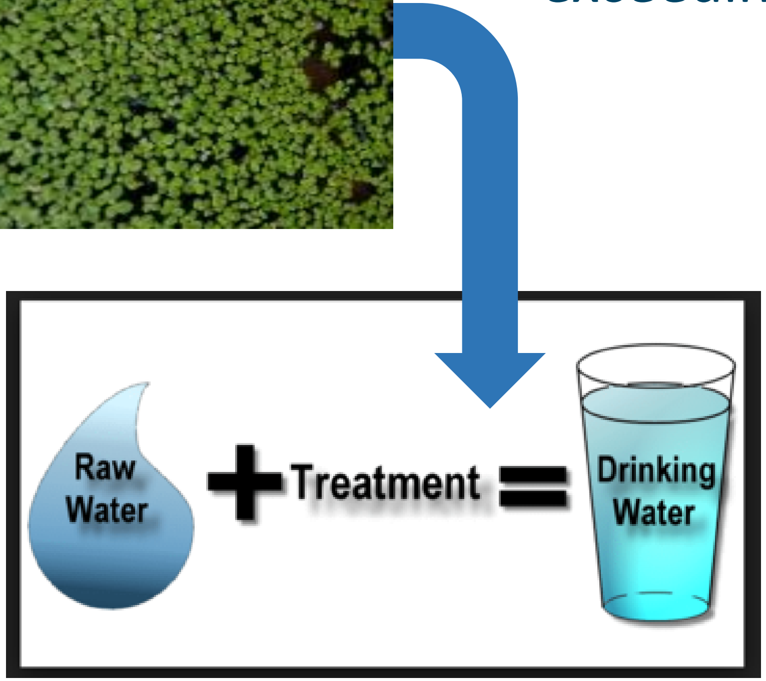
Water Depth: mm's – m's





Wastewater Treatment with Duckweed

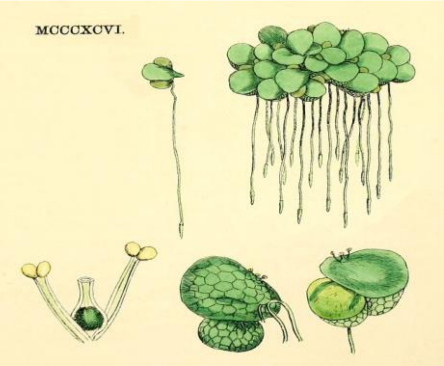


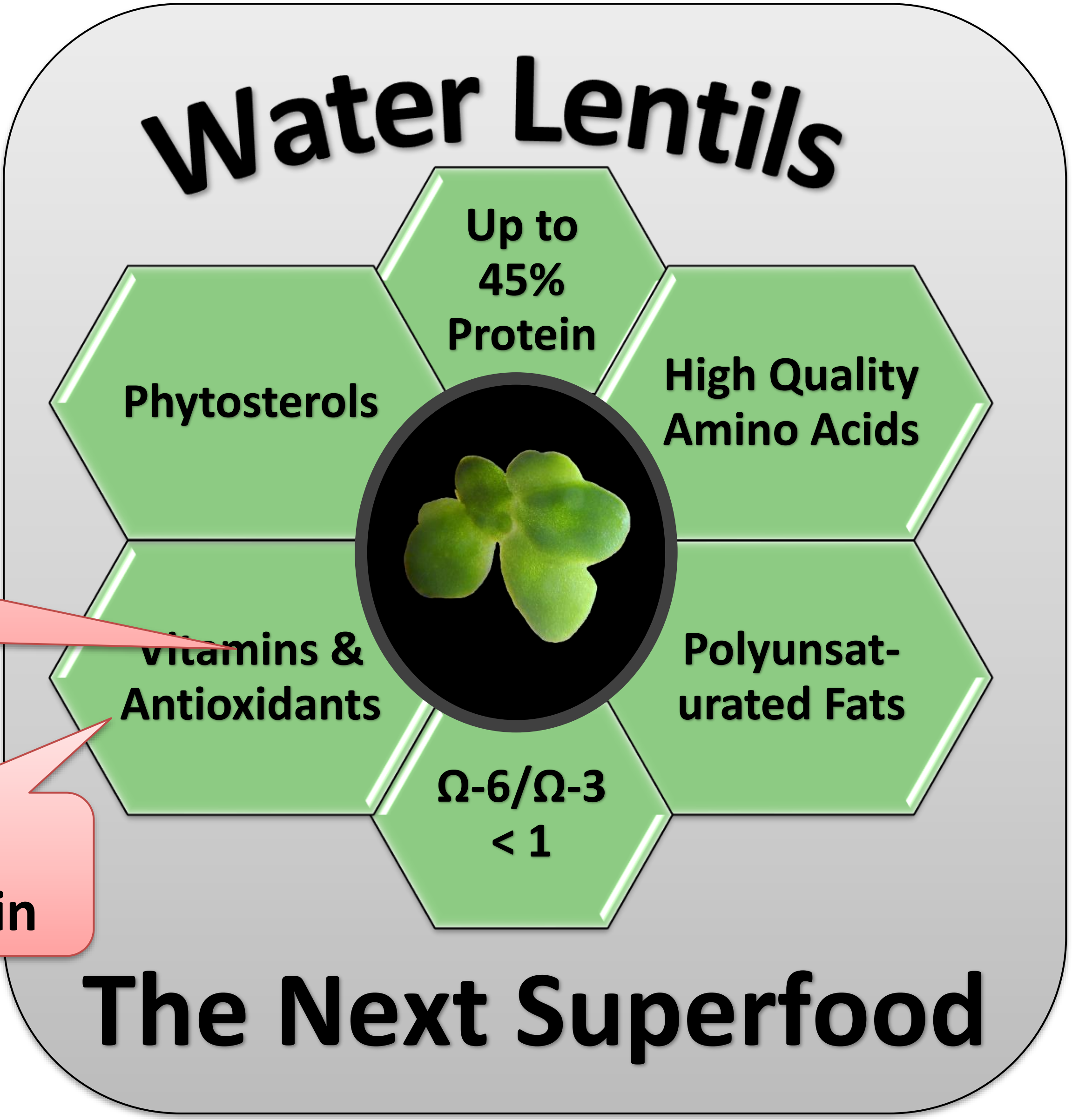


Lemna populated lagoons treat sewage in as many as 100 facilities around the world, with effluent often exceeding US water quality standards.

Leng, 1999

(Iqbal, 1999)




Water Lentils
Up to 45% Protein
Phytosterols
High Quality Amino Acids
Vitamins & Antioxidants
Polyunsat-urated Fats
Ω-6/Ω-3 < 1
Vitamin A C E
Lutein Zeaxanthin
The Next Superfood


PARABEL™
plantible™
HINOMAN
CULTIVATING NATURE'S WONDER
flo
BY ADVANCED GREENFARM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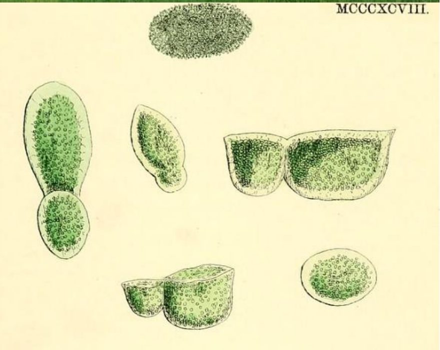
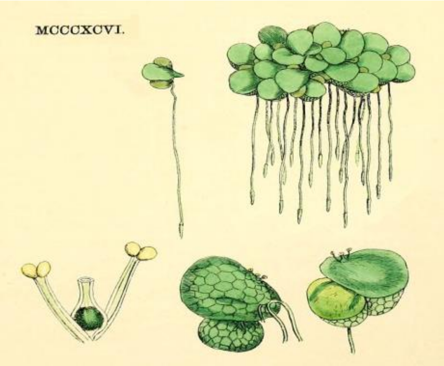
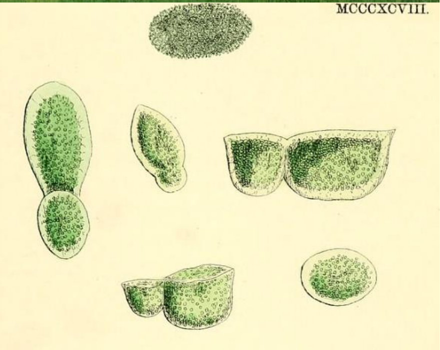


Holisticchefaca-demy.com

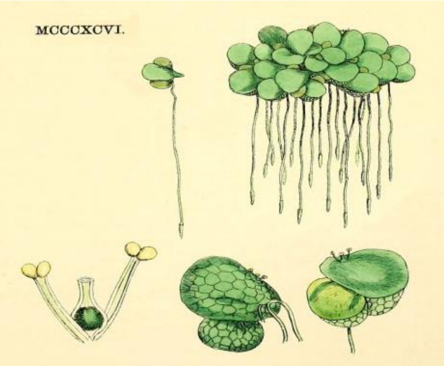
www.advancedgreenfarm.com

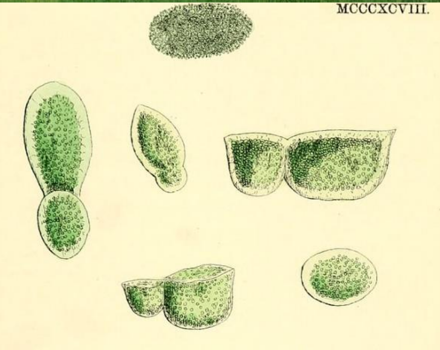




Duckweed Spaceflight Heritage

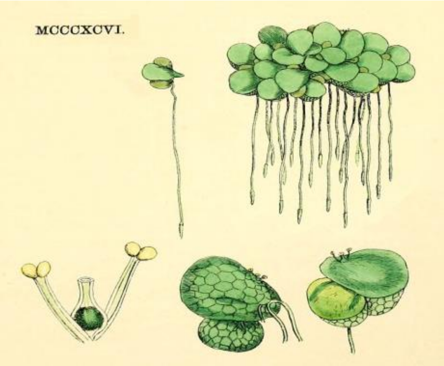
- **1966:** Orbiting Vehicle 1-4 (1st US space plant experiment & first successful measurement of plant photosynthesis in space)
- **1982:** NASA STS-4 Getaway Special
- **1987:** Russian satellite Bion 8
- **1982:** NASA STS-4 Getaway Special
- **1992:** Russian satellite Bion 10
- **1994**: NASA STS-60 Getaway Special
- **1995:** STS-67: influence of µg on duckweed anatomy - *(Eichorn & Fritsche, 1996)*
- **2020:** Blue Origin NS-13, Space Lab® µG-LilyPond Experiment
- **2022:** Blue Origin NS-23, Space Lab® µG-LilyPond Experiment *(did not reach microgravity due to booster abort)*





“One of the most attractive higher plants” for space life support

Yuan & Xu, 2016



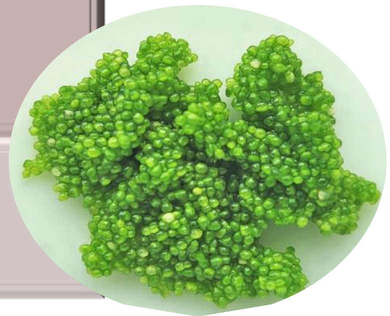
100% Harvest Index	Thrives in High CO_2
Can Eat Raw	24-hr Light
Highly Nutritious	Grows in Dark
Palatable	Dormant State
High Growth Rate	Shallow Water
Vegetative Budding	Prefers NH_3
Env. Robustness	Space Heritage

Thin (10 cm) stacked $1 m^2$ trays ➔ $10 m^2$ growth area per $1 m^3$

0.15-0.25 kg DM (68-112 g protein) per day

Space Production Challenges

CHALLENGE	GOAL
Volume Efficiency	• Maximize yield/volume
Water Delivery	• Maintain stable thin film in microgravity
Daily Harvest Requirements	• Minimize crew time for operation • Separate & recycle H2O in microgravity
Thermal Control	• Maintain stable water temp • Dissipate radiant heat from lighting
Nutritional Quality	• Maximize protein • Reduce oxalic acid (no issue w/ *Wolffia*) • Stimulate antioxidant production
Biofilm, Deposits	• Maintain water flow • Prevent pathogen infection
Crop Loss or Dormancy	• Rapid crop restart if system fails or is unused
Food Preparation & Storage	• Maintain nutritional value • Palatability & Acceptability



μG-LilyPond™ – Thin Film Vertical Farm for Microgravity

Enclosure
22” (L) × 18” (W) × 22” (H)
Dual MLE, with Ortho-Grid

Passively Fed Growth Bed
×2 Dual sided 15” × 15” trays
0.5 m^2 Total Growth Area
Vertically Stacked
0.5” Deep Water Film

Atmosphere and Thermal & Humidity Control
Direct Cabin CO_2 Utilization
Reduces to O_2
No Latent Heat Load
Heat Rejection via MTL

Close Canopy Lighting
Liquid Cooled LED Panels
Uniform Coverage, 1” away
$\geq$ 1200 μmol m^{-2} s^{-1} | $\sigma = \pm 5\%$
Efficient: 124W m^{-2} @300 μE

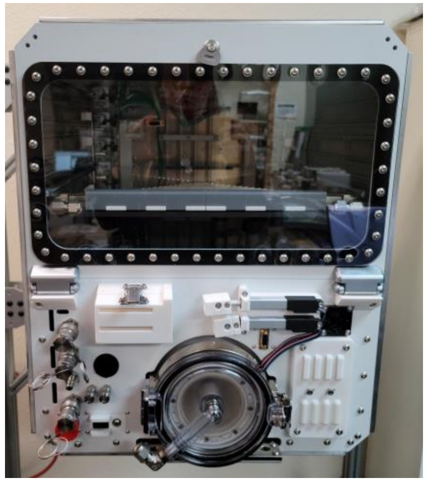
Command & Data Handling
Space Lab Perseus Lite
Processing Unit
for Autonomous Control
Microprocessor & FPGA
Xilinx Artix-7

Autonomous Water & Nutrient Recycling
Condensate Recovery
Mass-Balance Nutrient Replenishment

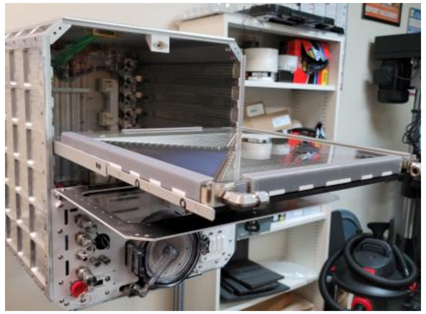
Microgravity Compatible Rotary Sieve
3-Phase Separator
Collects Biomass in Filter Bag

Autonomous Pathogen & Biofilm Control

µG-LilyPond™ Development



Phase II EDU



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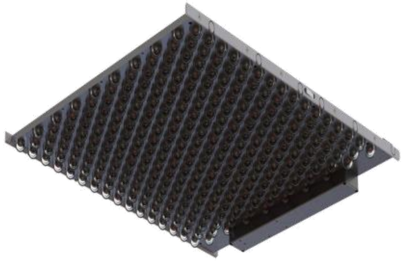
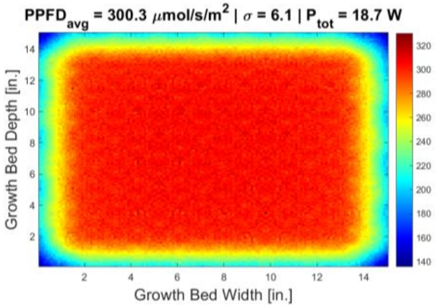
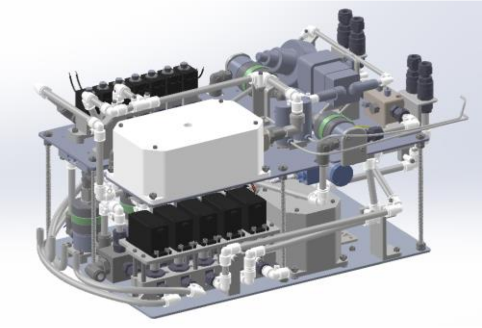
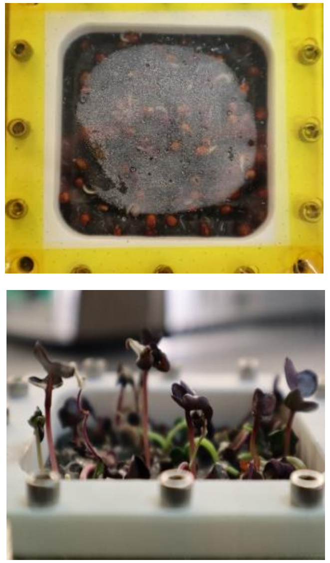




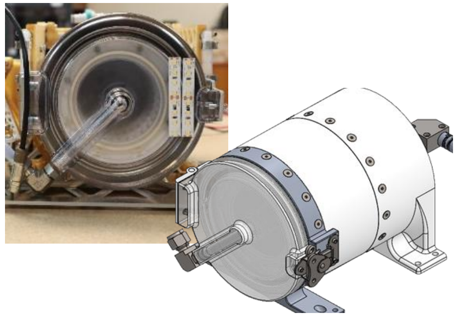
Close Canopy Lighting



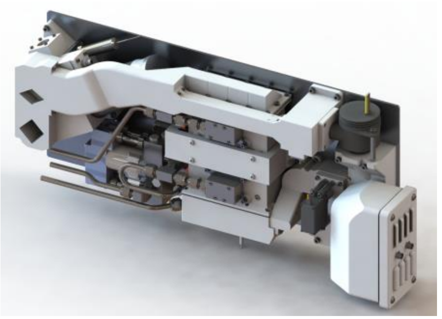
Compact Water Transport Loop (EDU)



Microgreens on Growth Bed Test Article



3-Phase Separator for Water Lentil Harvest



Atmosphere Control

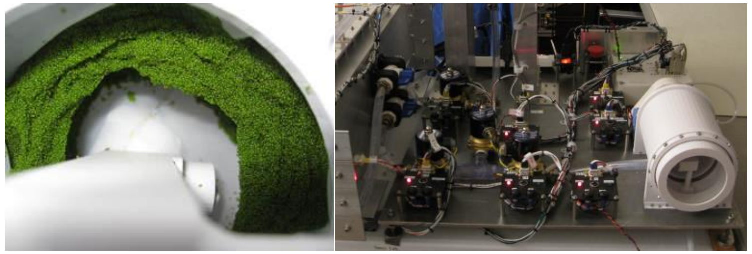
Capillary Fed Growth Bed

NASA STTR Phase I, II, III

2017-2021

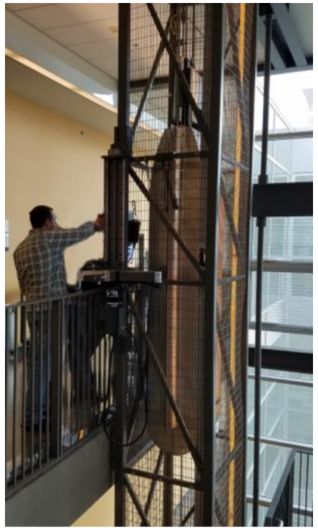
Demonstrate Feasibility & Advance TRL:

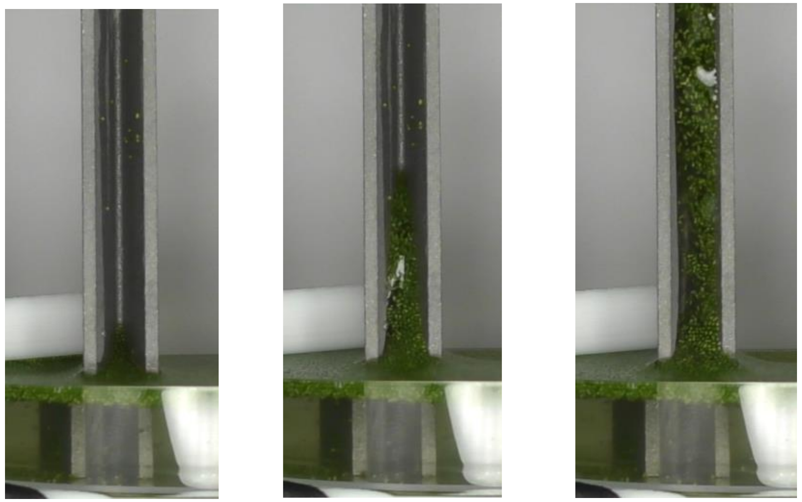
- Passive water delivery in µg
- Continuous water lentil harvest
- Water recycling & conditioning (recirculating hydroponics)
- Close canopy lighting
- Radiant heat dissipation to MTL
- Growth bed extensibility to rooted land plants



Phase I Harvester Prototypes

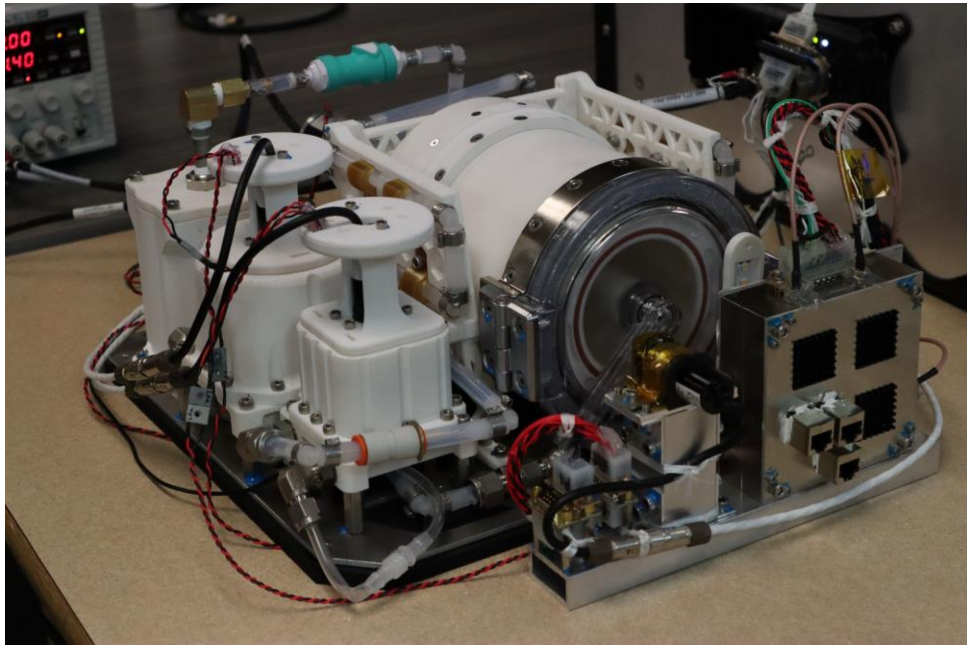
Microgravity Testing of µG-LilyPond Growth Bed

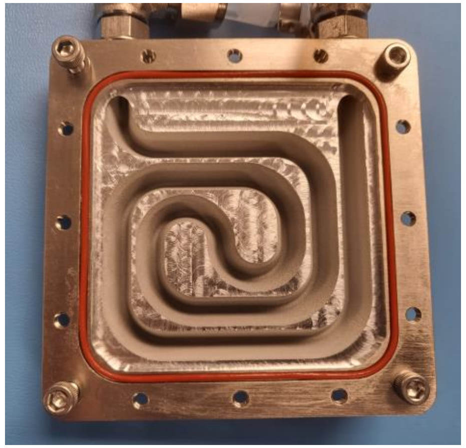




a) Pre-drop b) post-release c) end of drop

Drop Tower Results For Additive Manufactured, Shot Peened Grade 5 Ti Pre-wetted Test Article With 10 Degree Half Angle





Blue Origin NS13 & NS23 Suborbital Flight Experiment for µG-LilyPond Growth Bed and Harvester

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