# Challenges of Greenhouse on Mars

Mahsa Moghimi Esfandabadi

**M.S. in Space Architecture**
**Sasakawa International Center for Space Architecture (SICSA)**

**Committee members:**
**Prof. Larry Bell**
**Prof. Olga Bannova**
**Prof. Larry Toups**
**Prof. Kriss Kennedy**

**Spring 2020**

# This Would Not Be Possible Without Your Help

| | |
|---|---|
| Prof. Larry Bell | Mom, Mahtab |
| Prof. Olga Bannova | Dad, Mohammad |
| Prof. Larry Toups | Gregory Davidson |
| Prof. Kriss Kennedy | Tara Bisharat |

# Preliminaries

## Vision

- Creating the multifunctional greenhouse space to support the physical and psychological needs of the crew during the long term mission on mars

## Goals

- Taking advantage of utilizing human waste for the composting system
- Designing a complete greenhouse module with pre and post-harvesting lab
- Maximizing flexibility and lowering redundancy in different modes (operation, hibernation and power-off modes)

## Strategies

- Maximizing greenhouse space and volume
- Utilizing one launch vehicle to deliver the system
- Analyzing various architecture
- Analyzing the folded greenhouse module in the payload shroud
- Optimizing core size and inflatable architecture
- Minimizing site preparation
- Increasing the quality of time spent at the greenhouse by the crew

## Constraints

- Payload shroud size restrictions
- Crew movement with the oxygen tank
- Exterior structure support for inflatables

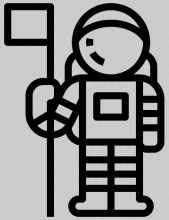
## Greenhouse

### What to grow?
Plant list

### How to grow?
Cultivation process, methods and tools

### Where to grow?
The greenhouse architecture

## Crew



### What to eat?
Menu and Culture

### How to eat?
Post harvesting process, cooking and recycling

### Where to eat?
The greenhouse's human factors

# What to Grow

Plant Selection

# Plant Lists

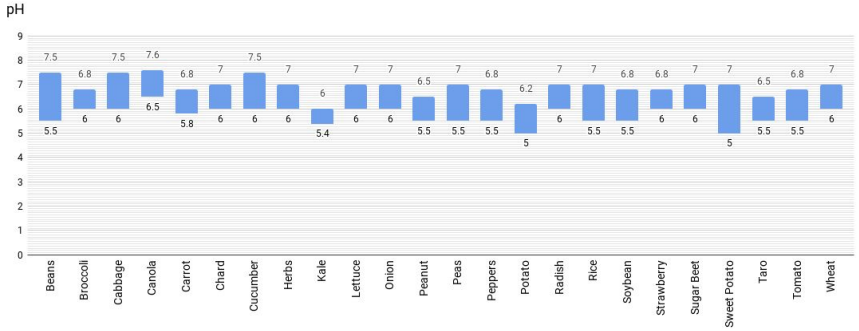
Menu Diversity and Culture

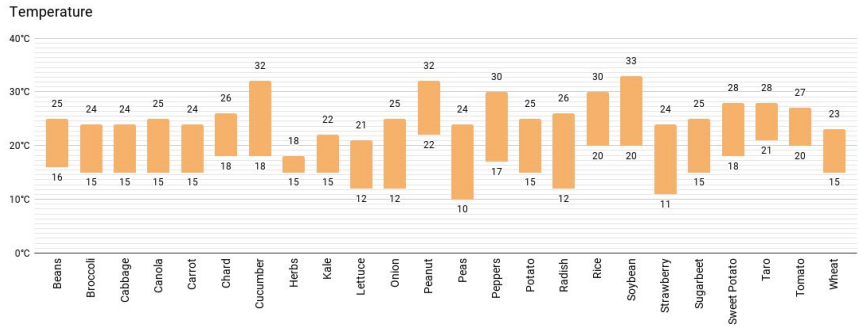
- Public Plant List
- Personal Plant List

| RAS Russia | NASA | ESA/Canada | NASA | NIES Japan | ESA/Canada | NASA |
|---|---|---|---|---|---|---|
| Beets | Beans | Beans | Beets | Beans | Alfalfa | Banana |
| Carrots | Broccoli | Beets | Broccoli | Cabbages | Beans | Barley |
| Cucumber | Corn | Broccoli | Corn | Carrots | Beets | Beans |
| Dill | Kale | Cabbages | Cucumber | Cucumber | Broccoli | Beets |
| Earth Almond | Mustard Greens | Carrots | Kale | Komatsuna | Cabbages | Broccoli |
| Kohlrabi | Oats | Cauliflower | Lettuce | Lettuce | Carrots | Cabbages |
| Onions | Peanuts | Kale | Mustard Greens | Mitsuba | Cauliflower | Cantaloupe |
| Peas | Peas | Lettuce | Oats | Onions | Chard | Carrots |
| Potato | Potato | Onions | Onions | Peanuts | Chilies | Cauliflower |
| Radishes | Rice | Potato | Peanuts | Peas | Cucumber | Celery |
| Tomato | Soybeans | Rice | Peas | Peppers | Herbs | Chard |
| Wheat | Turnip | Soybeans | Potato | Radishes | Kale | Chives |
| | Wheat | Spinach | Rice | Rice | Lettuce | Corn |
| | | Sweet Potato | Soybeans | Shiso | Mushrooms | Garlic |
| | | Wheat | Spinach | Shungiku | Onions | Grape |
| | | | Strawberries | Soybeans | Peanuts | Kale |
| | | | Sugar Beets | Spinach | Peas | Lettuce |
| | | | Sweet Potato | Sugar Beets | Peppers | Mint |
| | | | Tomato | Tomato | Potato | Oats |
| | | | Wheat | Turnip | Rice | Onions |
| | | | | | Soybeans | Parsley |
| | | | | | Spinach | Peanuts |
| | | | | | Squash | Peas |
| | | | | | Sweet Potato | Peppers |
| | | | | | Tomato | Potato |
| | | | | | Wheat | Rice |
| | | | | | | Rye |
| | | | | | | Soybeans |
| | | | | | | Spinach |
| | | | | | | Strawberries |
| | | | | | | Sugar Cane |
| | | | | | | Sweet Potato |
| | | | | | | Taro |
| | | | | | | Tea |
| | | | | | | Tomato |
| | | | | | | Wheat |

# Most Common Plants

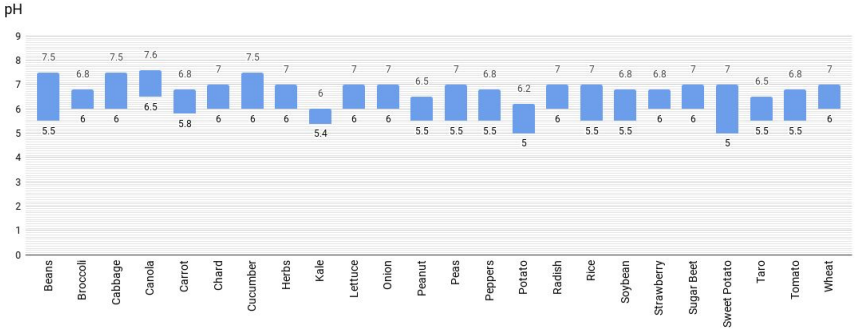
| Beans | Canola | Cucumber | Lettuce | Peanut | Radish | Strawberry | Taro |
|---|---|---|---|---|---|---|---|
| Broccoli | Carrot | Herbs | Onion | Peppers | Rice | Sugar Beet | Tomato |
| Cabbage | Chard | Kale | Peas | Potato | Soybean | Sweet potato | Wheat |

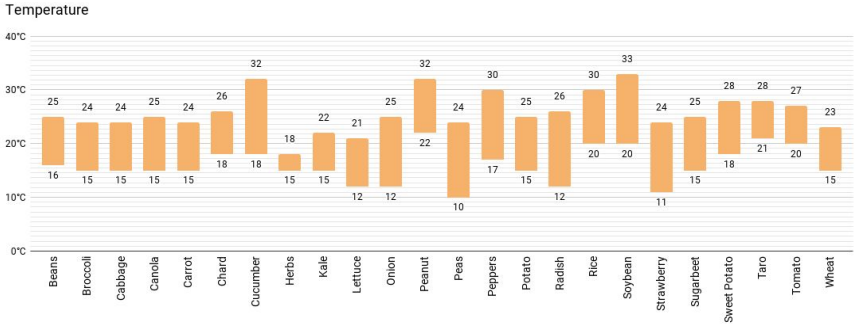


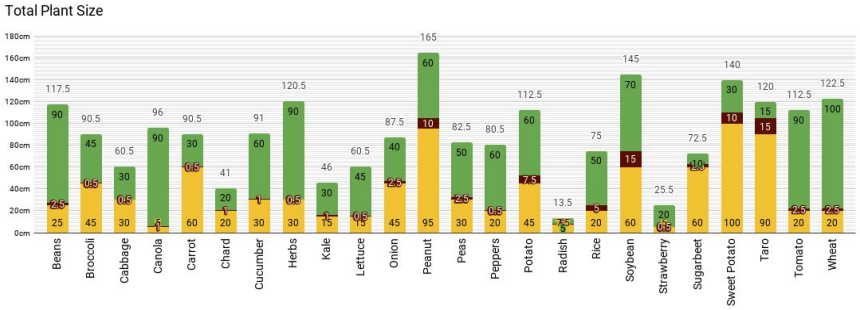
# Most Common Plants

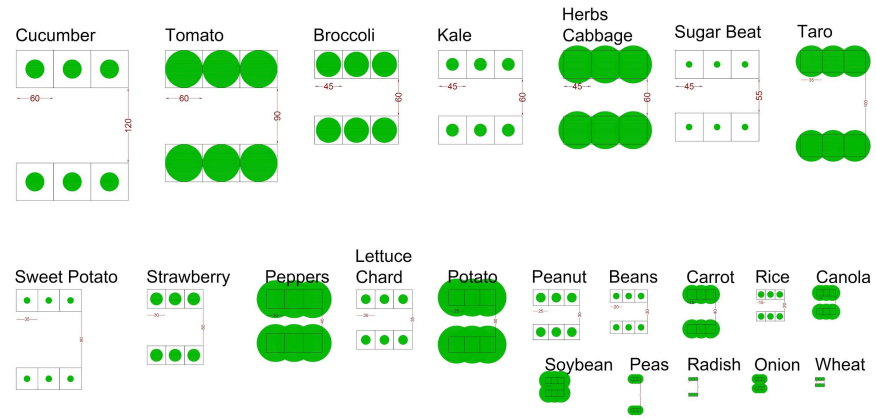
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Beans | Canola | Cucumber | Lettuce | Peanut | Radish | Strawberry | Taro |
| Broccoli | Carrot | Herbs | Onion | Peppers | Rice | Sugar Beet | Tomato |
| Cabbage | Chard | Kale | Peas | Potato | Soybean | Sweet potato | Wheat |

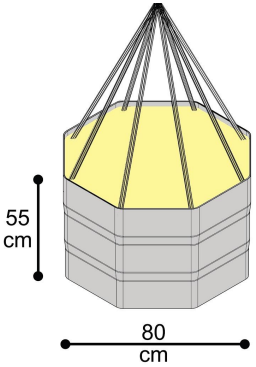


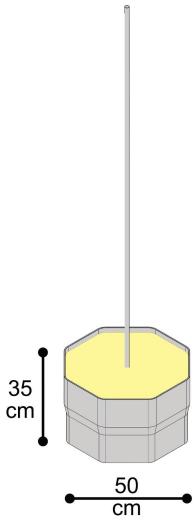
# Plants' Design Factor



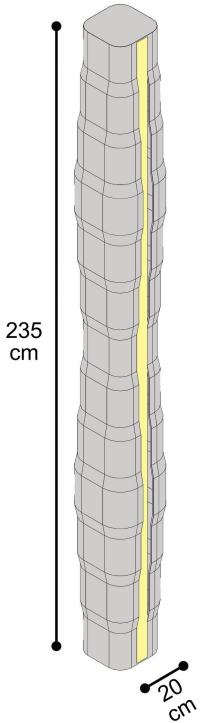



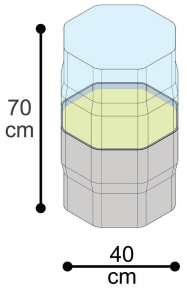

**Bracket**




**Trellis**




**Wall**




**Box**

# Energy and Agriculture Area

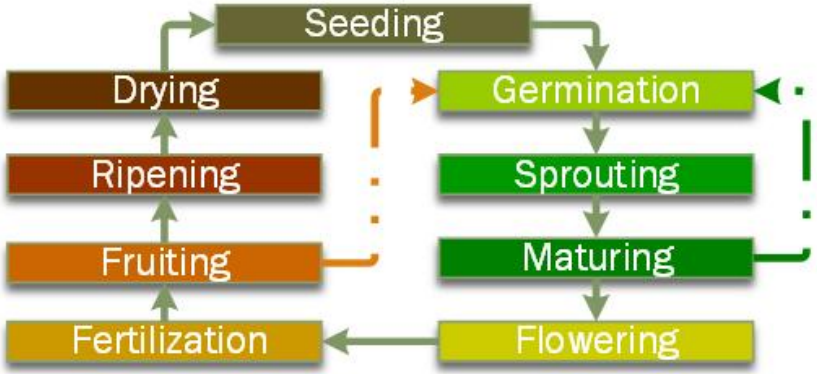
| | Intake Calories Per Day (kcal) | Required Calories Per Day (kcal) | Ratio of Intake to Required Calories (%) | Cultivation Area ($m^2$) |
|---|---|---|---|---|
| **NASA** | **1130** | **2700** | **60** | **46.5** |
| **Greenhouse** | **3000** | **3000** | **100** | **123.5** |

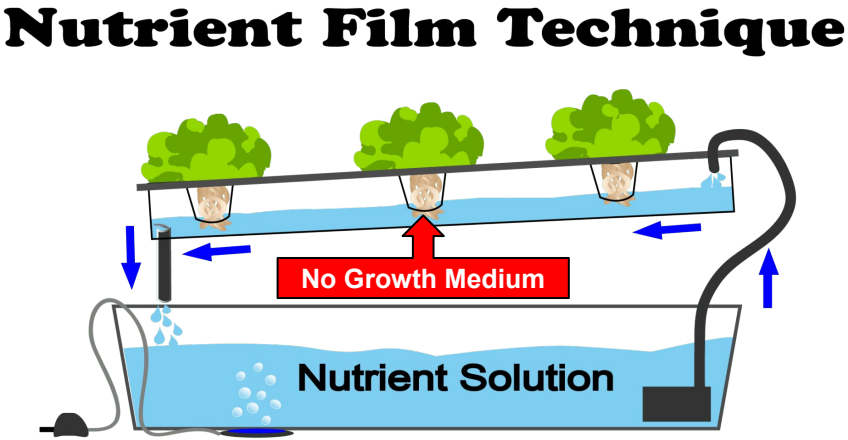
**4** Crew Need **494 $m^2$** Cultivation Area

# How to Grow

Cultivation Process, Methods and Tools

# Crop Cycle and Cultivation Method



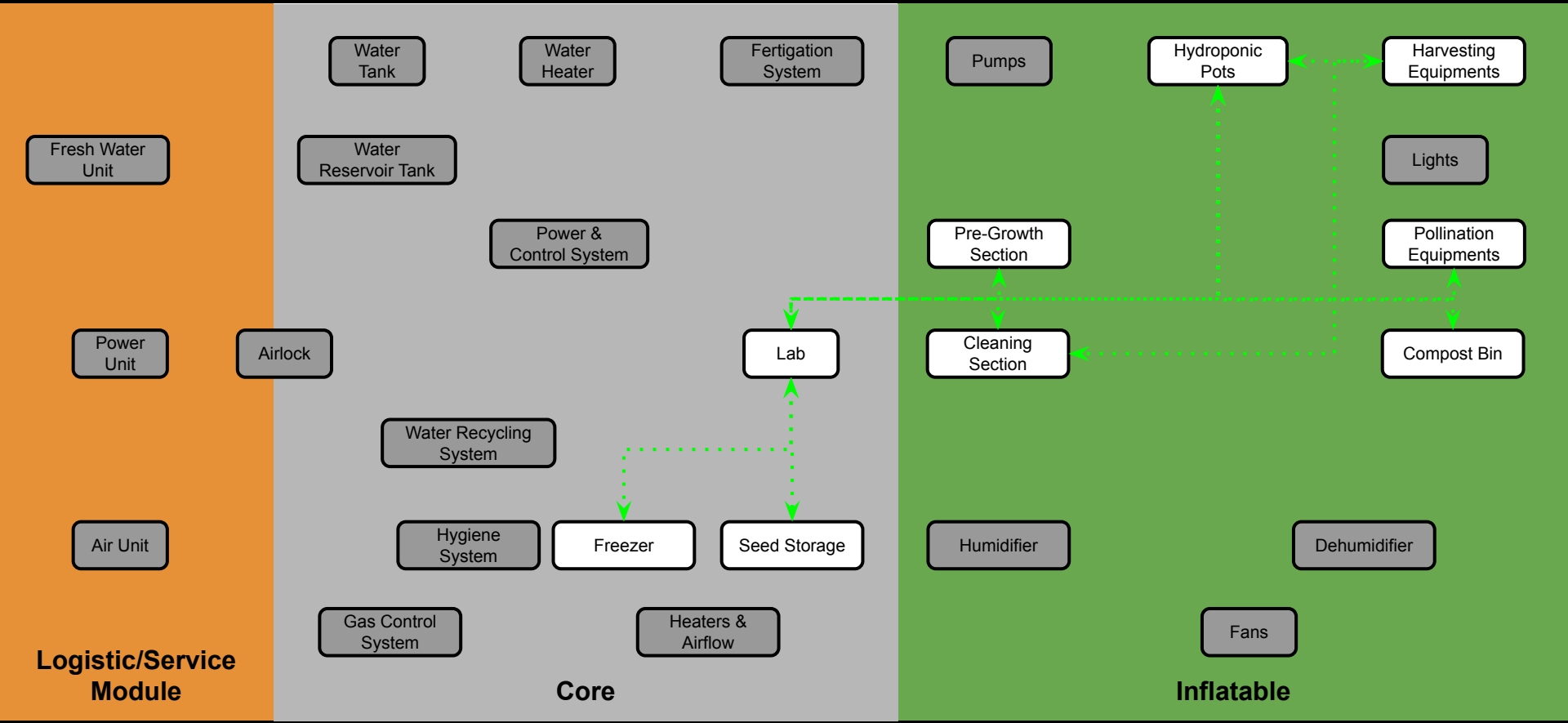



# Post Harvesting Process

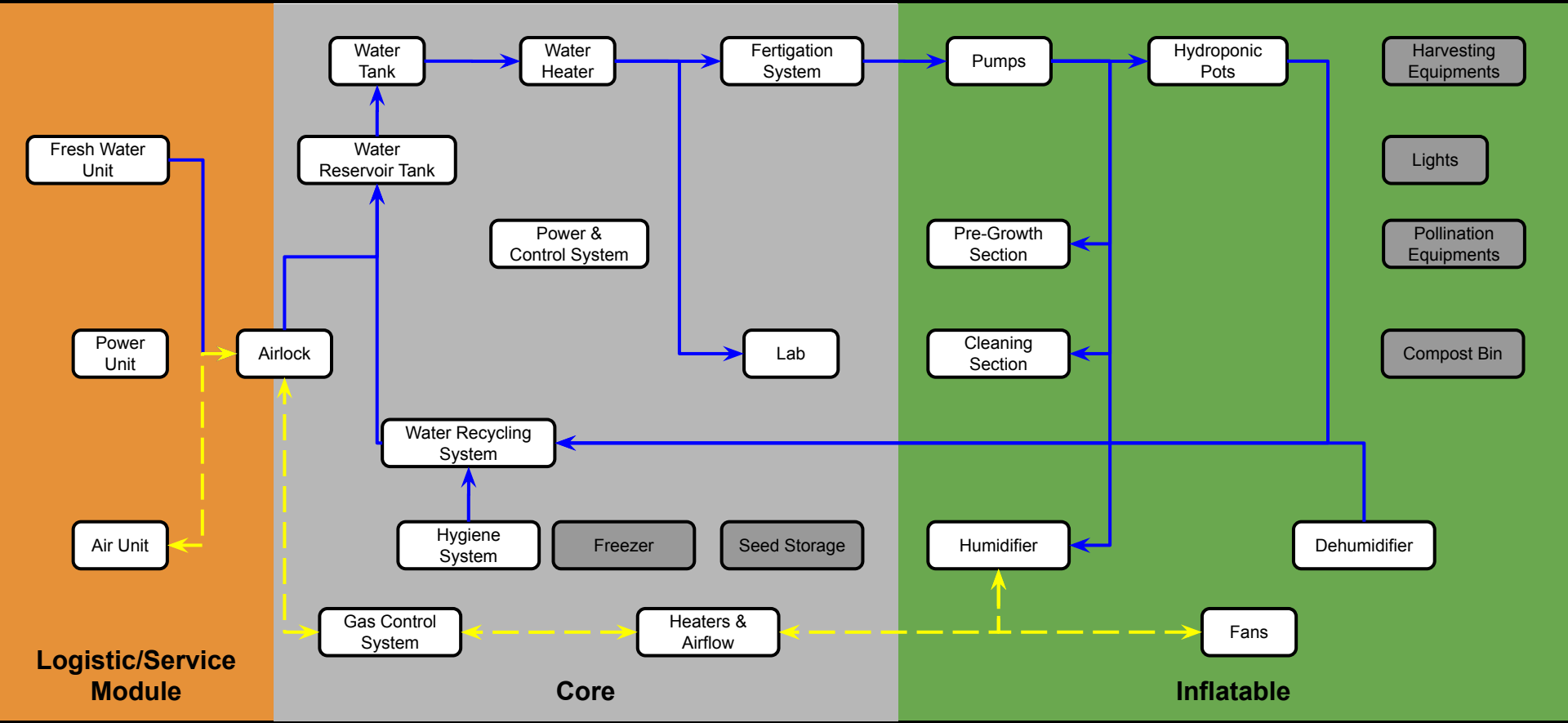
| Edible | Drying | Storing | Primary Processing | Secondary Processing | Product Evaluation | Packaging | Storing |
|---|---|---|---|---|---|---|---|
| Harvesting | | | Cleaning<br>Classification<br>Dehulling<br>Pounding<br>Grinding<br>Soaking<br>Winnowing<br>Drying<br>Sieving<br>Milling | Mixing<br>Cooking<br>Frying<br>Molding<br>Cutting<br>Extrusion | Quality Control<br>Standard<br>Recipes | Weighing<br>Labelling<br>Sealing | |

| Green Waste | Composting | Water Extracting | Nutrient Extracting |
|---|---|---|---|
| Mixed with Sewage Disposals | | | |

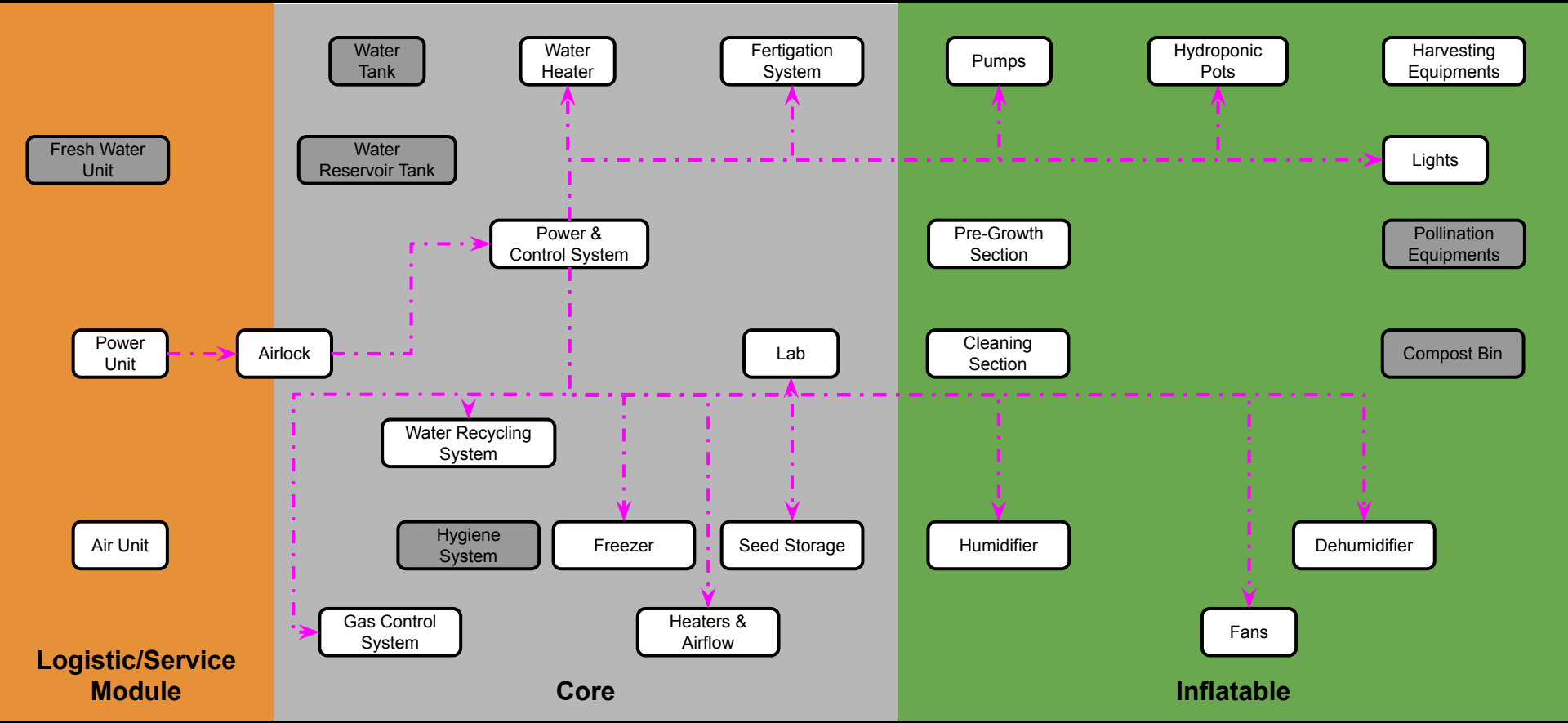
# Functional Allocation Diagram: Agriculture Systems



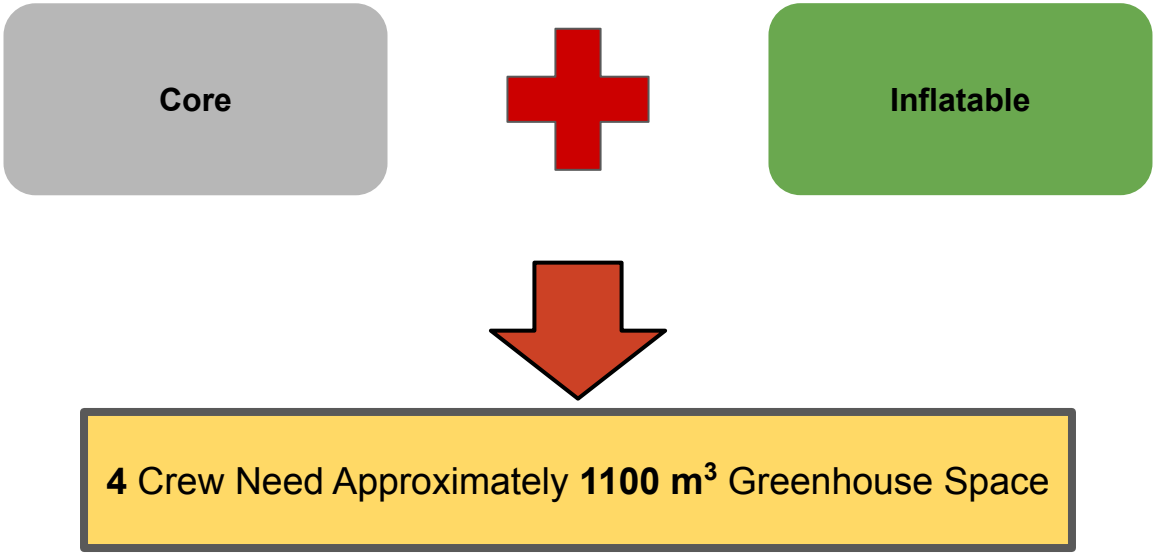
# Functional Allocation Diagram: Air and Water Systems



# Functional Allocation Diagram: Power and Control Systems



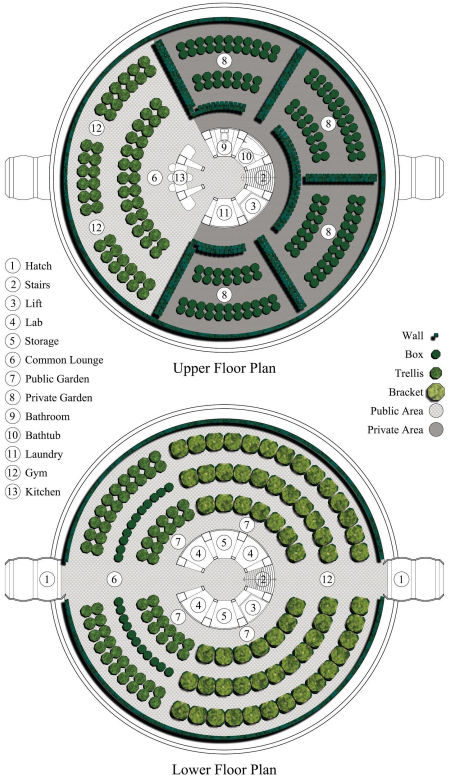
# Outcome

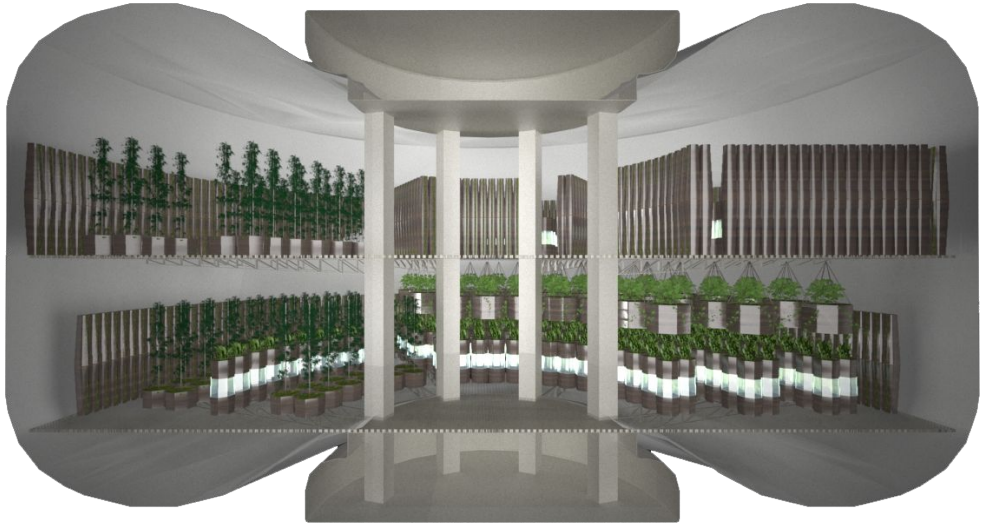

Core
Inflatable
4 Crew Need Approximately 1100 m3 Greenhouse Space

# Where to Grow

Greenhouse Architecture

# Previous Design

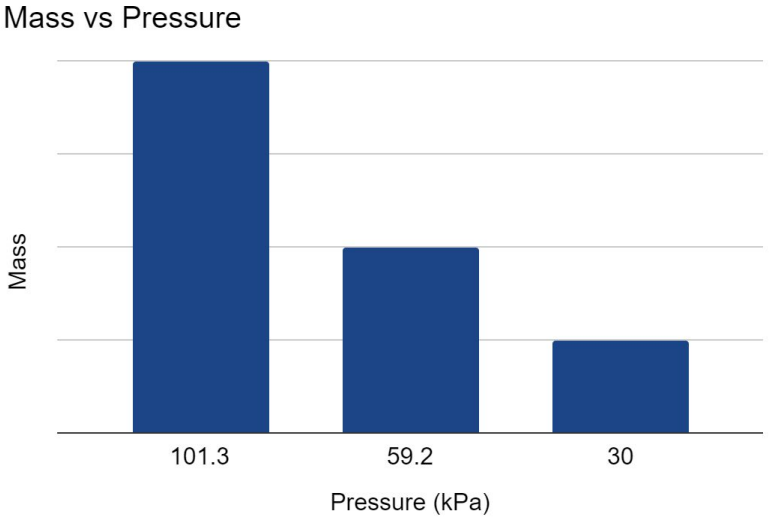


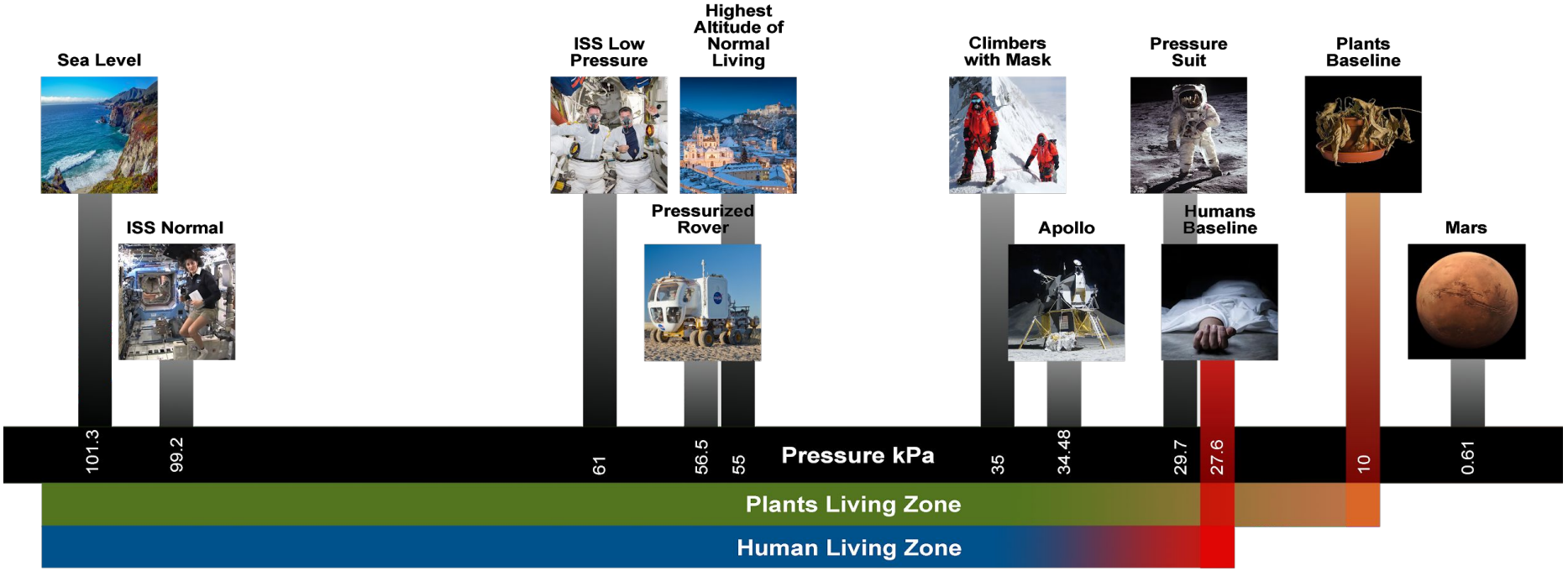
# Effect of Pressure Difference on Structure

| Pressure (kPa) | 101.3[1] | 59.2[2] | 30.0[2] |
|---|---|---|---|
| Kevlar Weight (kg/m$^2$) | 2.54 | 1.31 | 0.66 |

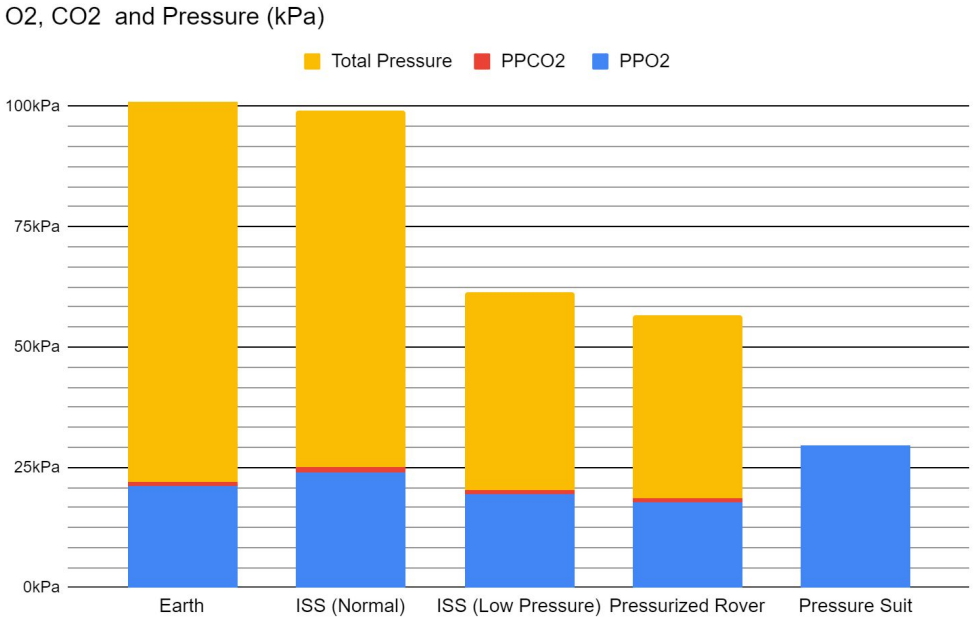

1- Seedhouse, E. (2015). Bigelow Aerospace. In Bigelow Aerospace. Springer International Publishing. https://doi.org/10.1007/978-3-319-05197-0
2- Hublitz, I., Henninger, D. L., Drake, B. G., & Eckart, P. (2004). Engineering concepts for inflatable Mars surface greenhouses. Advances in Space Research, 34(SPEC. ISS.), 1546–1551. https://doi.org/10.1016/j.asr.2004.06.002

# Total Pressure Examples



# Partial Pressure of O2, Partial Pressure of CO2 and Total Pressure

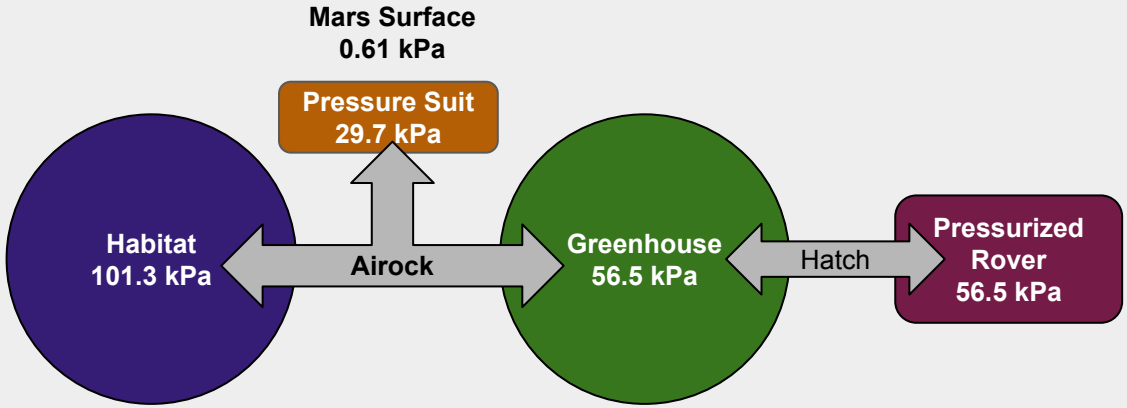



# Surface EVA Scenarios Timelines

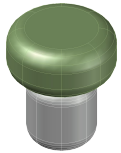
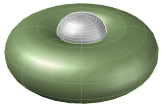
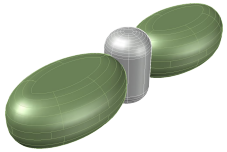
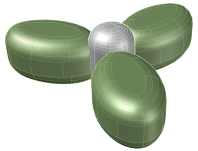
| Scenario 3x2h | Total Pre-Breathe Time |
|---|---|
| EVA EVA EVA | 7:20 |
| **Scenario 1x8h** | |
| EVA | 4:40 |

101.3 kPa | 56.5 kPa | 29.7 kPa | EVA

Each Unit is 20 Minutes

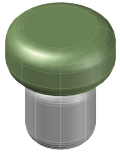


# Mass Estimation

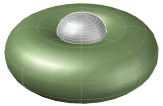





| | Mushroom | Torus | 2 Petals | 3 Petals |
|---|---|---|---|---|
| Inflatable Mass (kg) | 1024 | 1462 | 1606 | 1719 |
| Core Mass (kg) | 15176 | 8135 | 8135 | 8135 |
| Airlock/Suitport (kg) | 600 | 600 | 600 | 600 |
| Hatch (kg) | 230 | 230 | 345 | 460 |
| **Total Mass (kg)** | **17030** | **10427** | **10686** | **10914** |
| **Total Mass (ton)** | **17.0** | **10.4** | **10.7** | **10.9** |

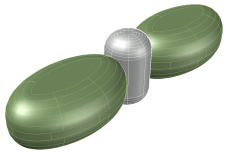
# Greenhouse Geometries



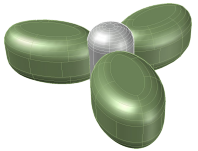
Mushroom



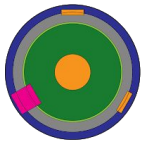
Torus

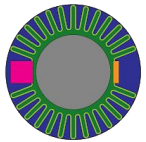


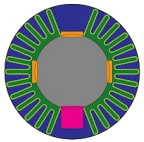
2 Petals

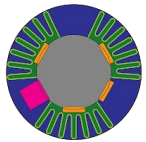


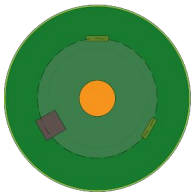
3 Petals

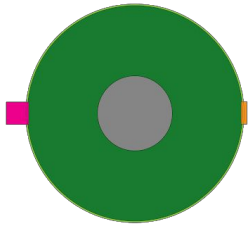


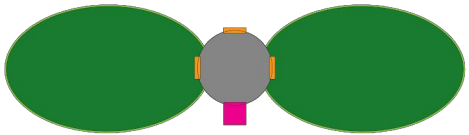


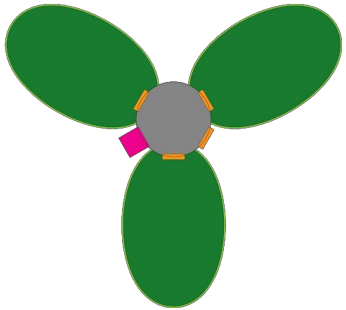






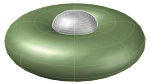




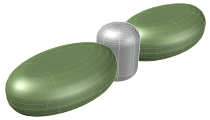


# Usable Area Estimation

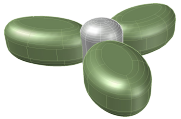
**Mushroom**



**Torus**

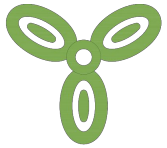


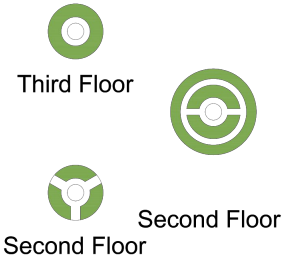
**2 Petals**



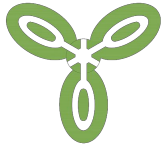
**3 Petals**



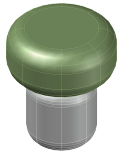
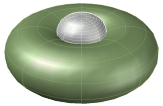
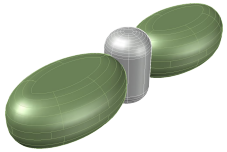
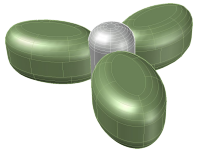




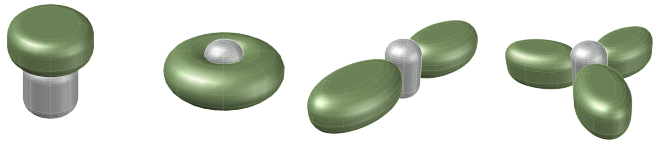


# Space Efficiency

| | Mushroom | Torus | 2 Petals | 3 Petals |
|---|---|---|---|---|
| Total Inflatable Area | 316.7 | 476.64 | 437.82 | 434.52 |
| Total Core Area | 185.46 | 77.78 | 77.78 | 77.78 |
| **Total Area** | **502.16** | **554.42** | **515.6** | **512.3** |
| Usable Area Level 1 | 30.67 | 108.71 | 77.82 | 81.04 |
| Usable Area Level 2 | 80.33 | 121.92 | 149.89 | 141.15 |
| Usable Area Level 3 | 80.33 | 108.71 | 158.36 | 152.21 |
| Usable Area Core | 122 | 0 | 0 | 0 |
| **Total Usable Area** | **313.33** | **339.34** | **386.07** | **374.4** |
| **Space Efficiency (%)** | **62** | **61** | **75** | **73** |

# Design Criteria



Most Preferable

Moderately Preferable

Least Preferable

| | | Mushroom | Torus | 2 Petals | 3 Petals |
|---|---|---|---|---|---|
| **Operation** | Space Efficiency | | | | |
| | Space Modification | | | | |
| **Hibernation** | Partial Operation | | | | |
| | Resource Consumption | | | | |
| **Emergency** | Crop Loss | | | | |
| | Functionality | | | | |
| **Physical Properties** | Mass | | | | |
| | Deployment | | | | |
| | Structure Assembly | | | | |
| | Systems Assembly | | | | |
| **Human Factors** | Accessibility | | | | |
| | Personal Area | | | | |

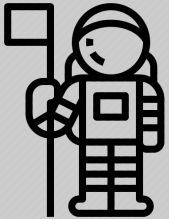

Conclusion

## Greenhouse

**What to grow?**

## Crew

**What to eat?**

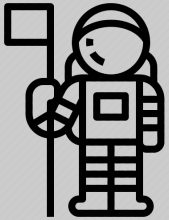


## Greenhouse

**What to grow?**

## Crew

**What to eat?**

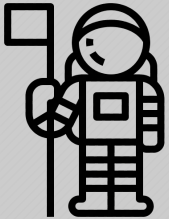


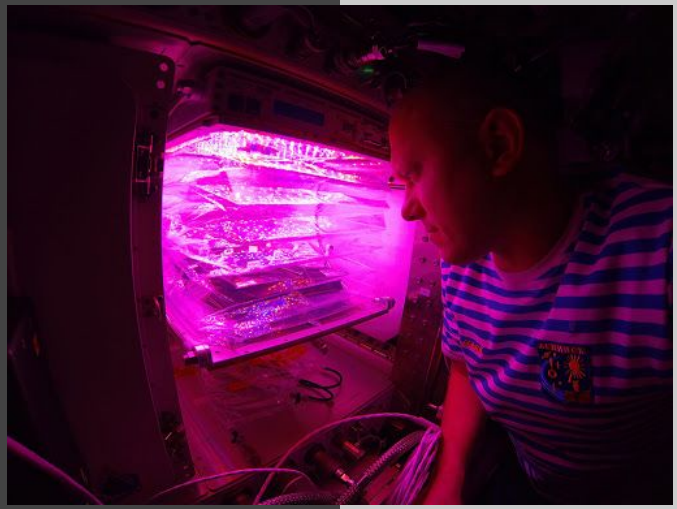
## Greenhouse

**How to grow?**

## Crew

**How to eat?**



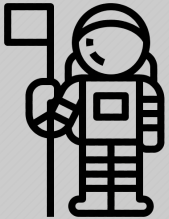


## Greenhouse

**How to grow?**

## Crew

**How to eat?**



Greenhouse

**Where to grow?**

Crew

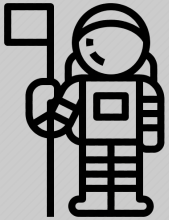
**Where to eat?**

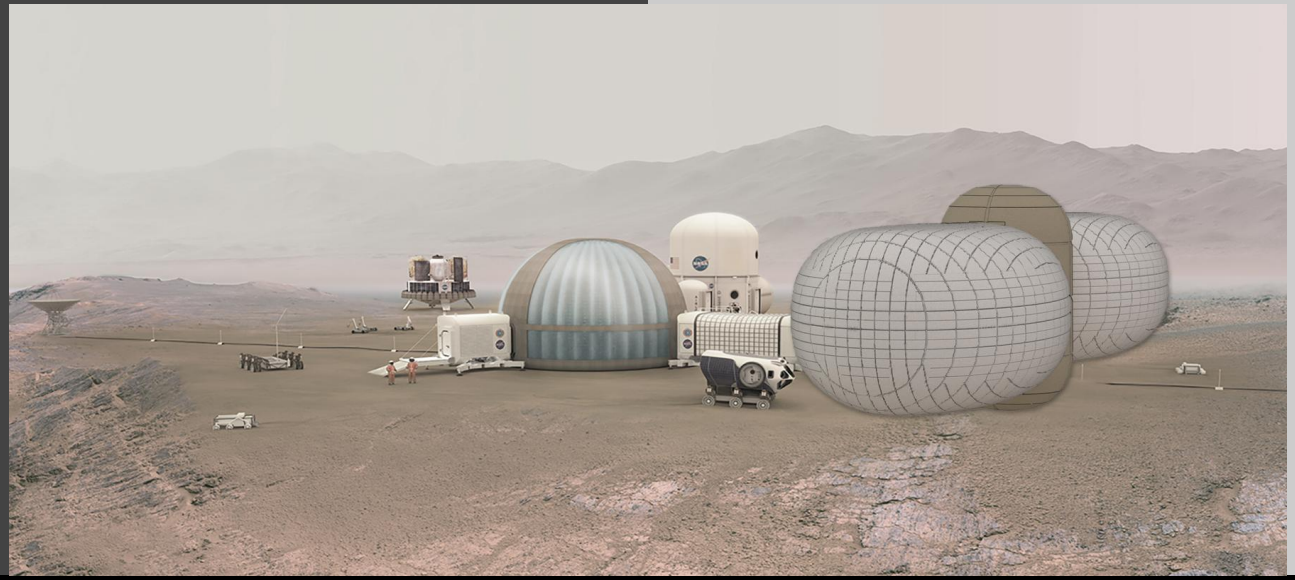
## Greenhouse

**Where to grow?**

## Crew

**Where to eat?**





## Thank you


Contact:
mesfand@uh.edu
mesfand@mit.edu
mesfand@spacearchitect.org