Engineering Services Contract

Partnering To Engineer the Future

Space Farming

Challenges & Opportunities

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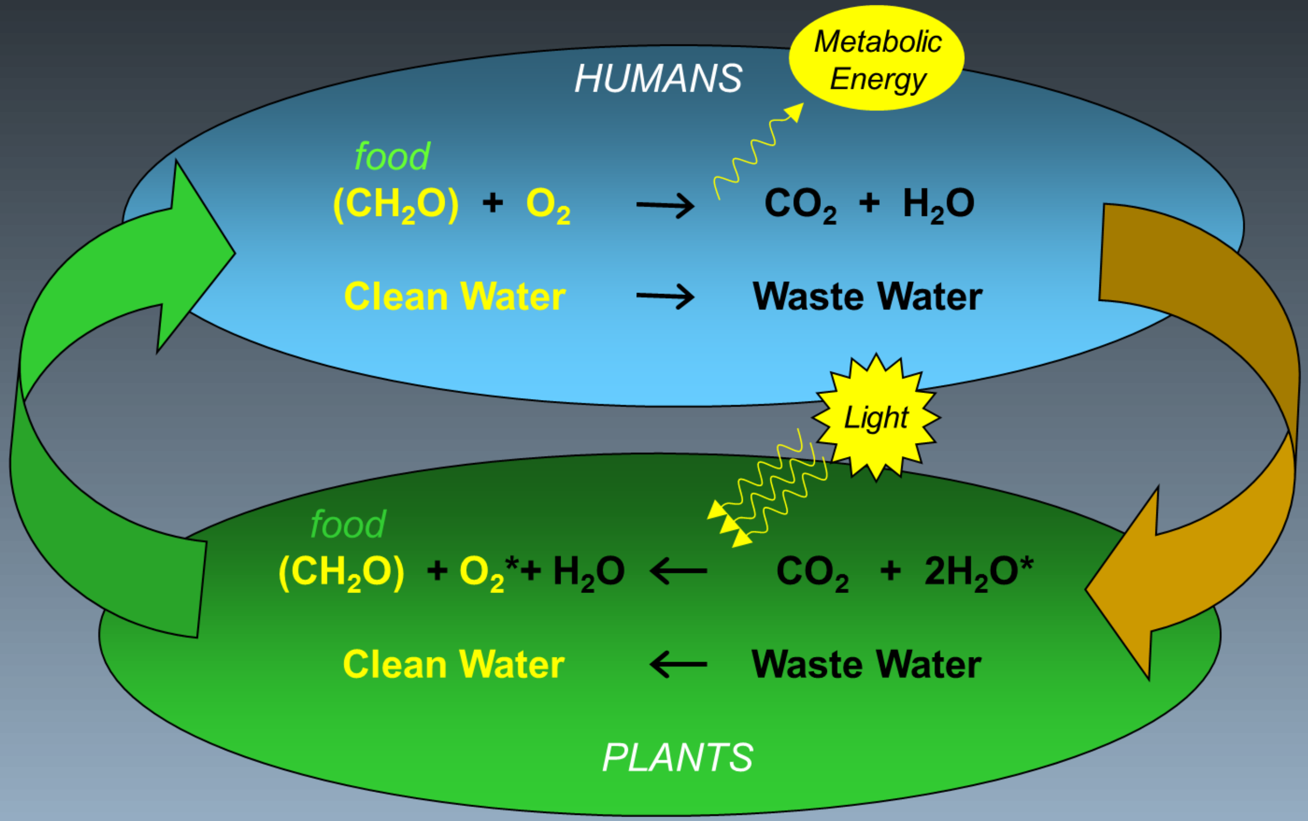
Kennedy Space Center, FL 32899

IFT 2017, June 25 -28, Las Vegas, NV

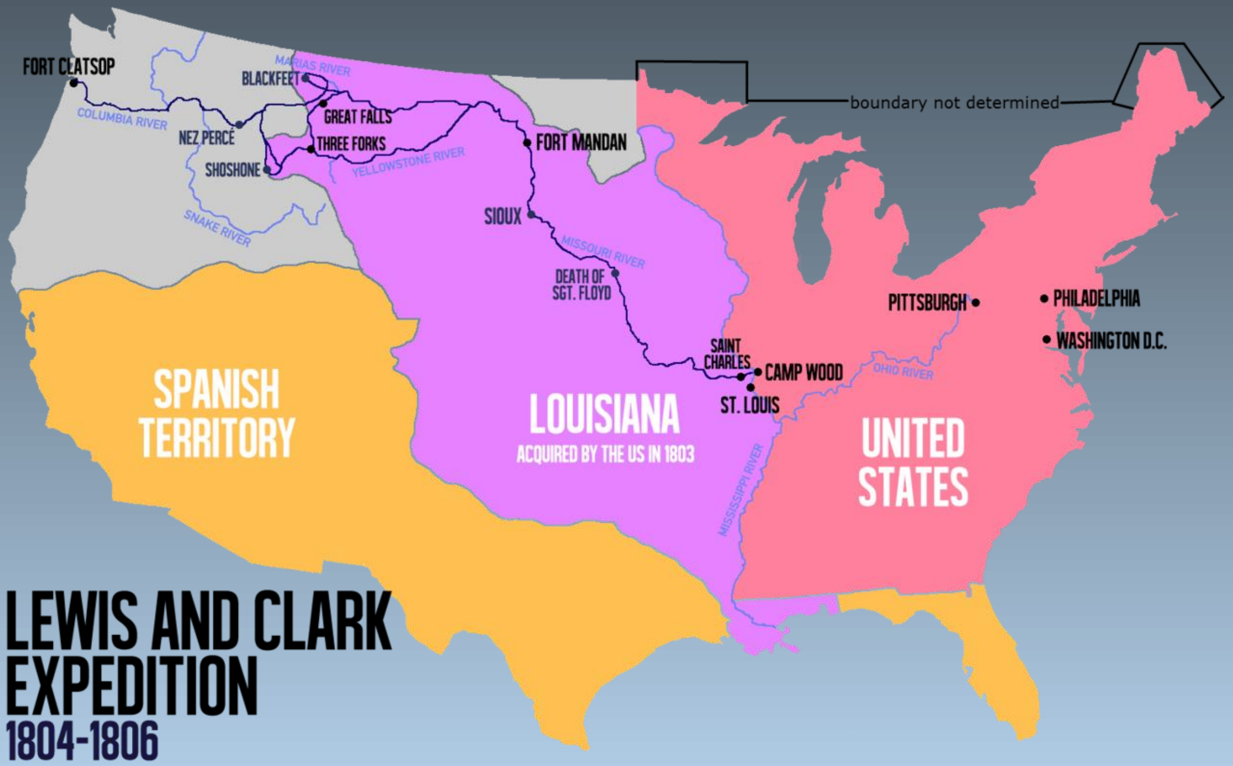
Earth = Our "Bioregenerative" Life Support System



Wheeler, 2016

On Earth, explorers ‘live off the land’

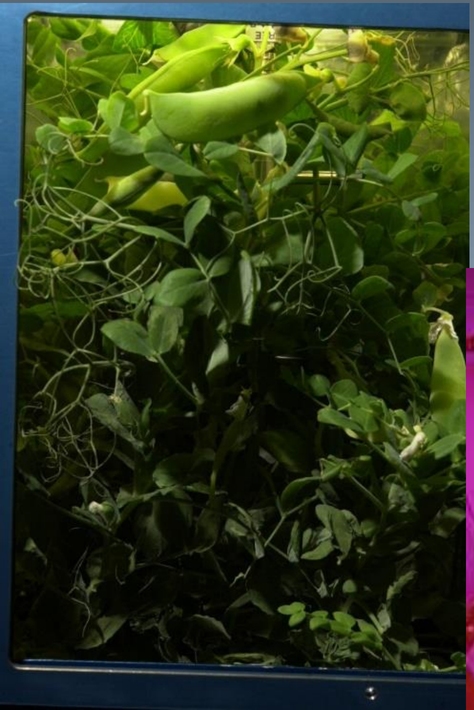
- Crew = 33
- 2 years – elk hunting and fishing
- Learned food technology from native tribes



In space, explorers need *in situ* food production

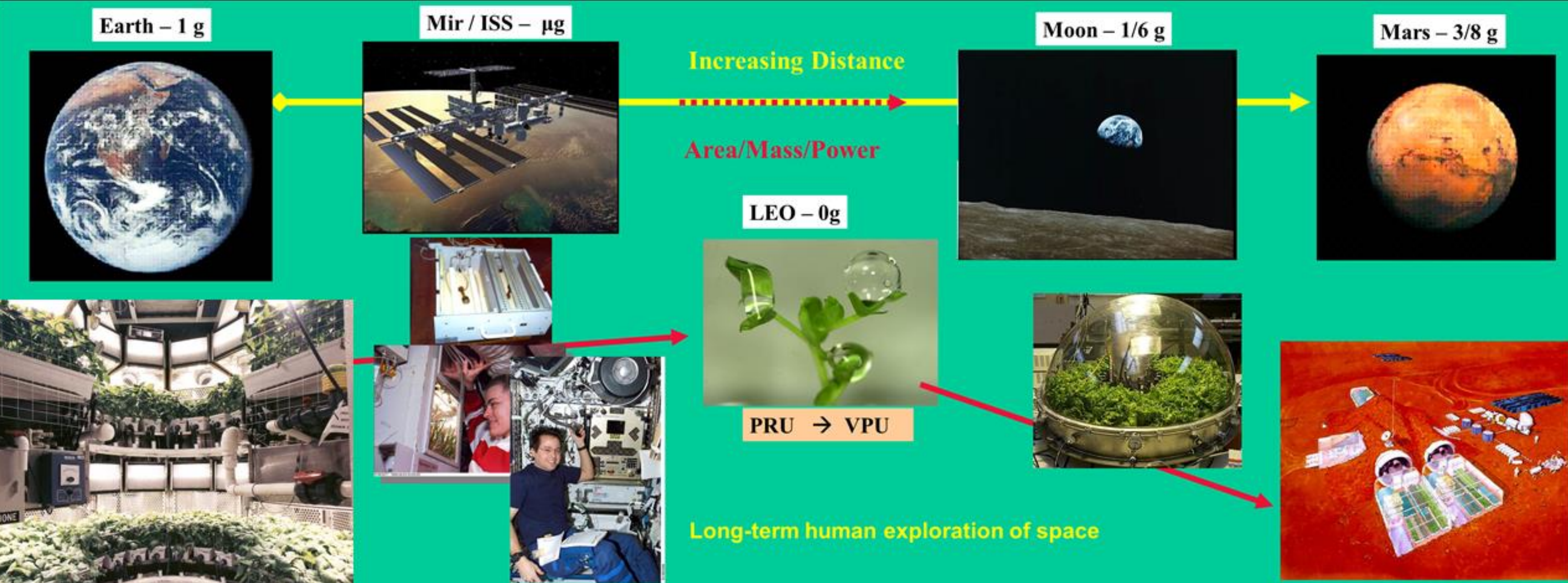
- Space Farming enables colonization of space
  - Sustainable: minimize logistics of resupply
  - Supplies: Light, CO_2, O_2, Nutrients, Water, Soil, Seeds, Plant chamber
  - Crew Psychological well-being: green Earth
  - Food Systems: palatable, nutritious and safe source of fresh food (limited shelf-life)

LADA



VEGGIE

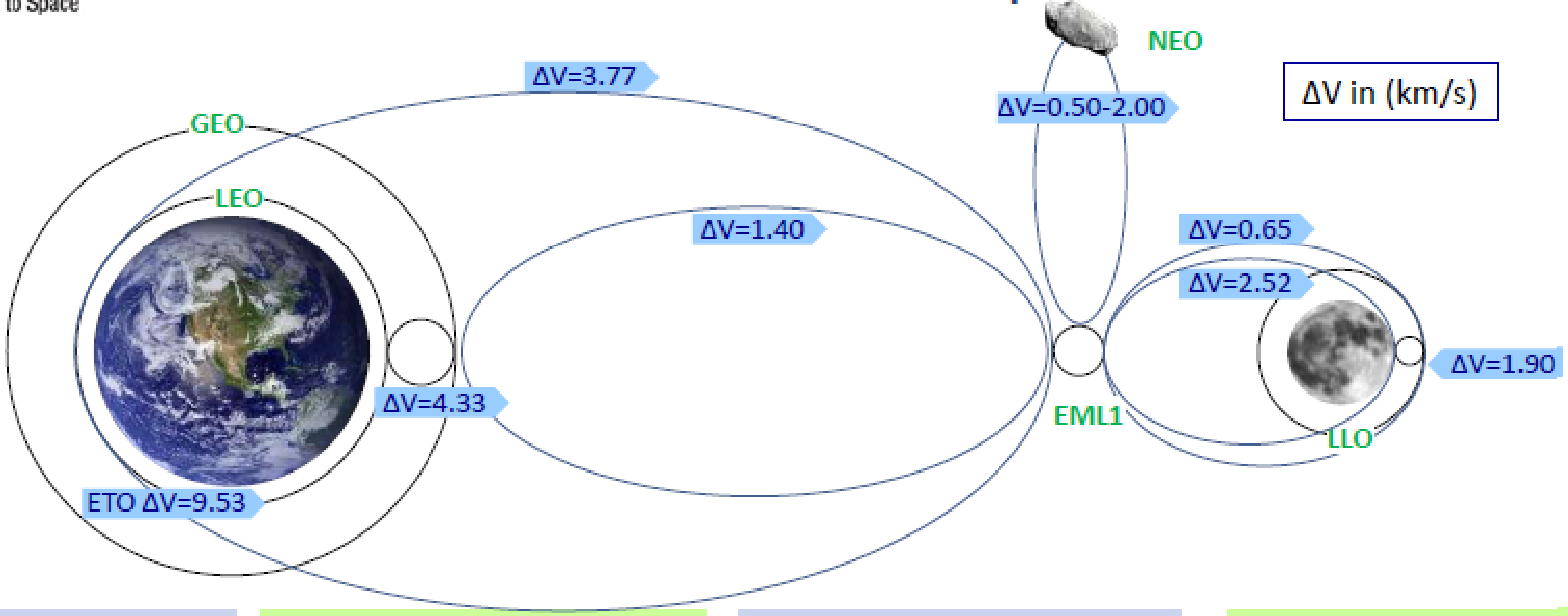
Task: adapt 1g agriculture to fractional g locations



Opportunities: Commercial Uses of Cislunar Space

America's Ride to Space

Cislunar Econosphere



LEO
ISS
Remote Sensing
Commercial Station
Communication
Space Control
Debris mitigation
Science
R&D
Tourism
Manufacturing
Propellant Transfer

GEO
Observation
Communication
Space Control
Debris Mitigation
Space Solar Power
Repair Station
Satellite Life extension
Harvesting

High Earth Orbit
Science / Astronomy
Communication Link
Way Station
Propellant Depots
Repair Station
Lunar Solar Power Sat
Manufacturing
Planetary Defense

Lunar Surface
Science/ Astronomy
•Lunar
•Observatory
Human Outpost
Tourism
Mining
•Oxygen/Water
•Regolith
•Rare Earth Elements
•HE3
Manufacturing
Fuel Depots

Existing market / Emerging market \ Future market

NASA – Prepares for missions to Mars

The Earth Reliant, Proving Ground, and Earth Independent periods are divided into phases, with a capstone demonstration defining the gate between each phase and the next. All activities are part of an integrated strategy that builds from experience gained in the Earth Reliant period, and informs objectives, capabilities, and missions in the Proving Ground and Earth Independent periods.

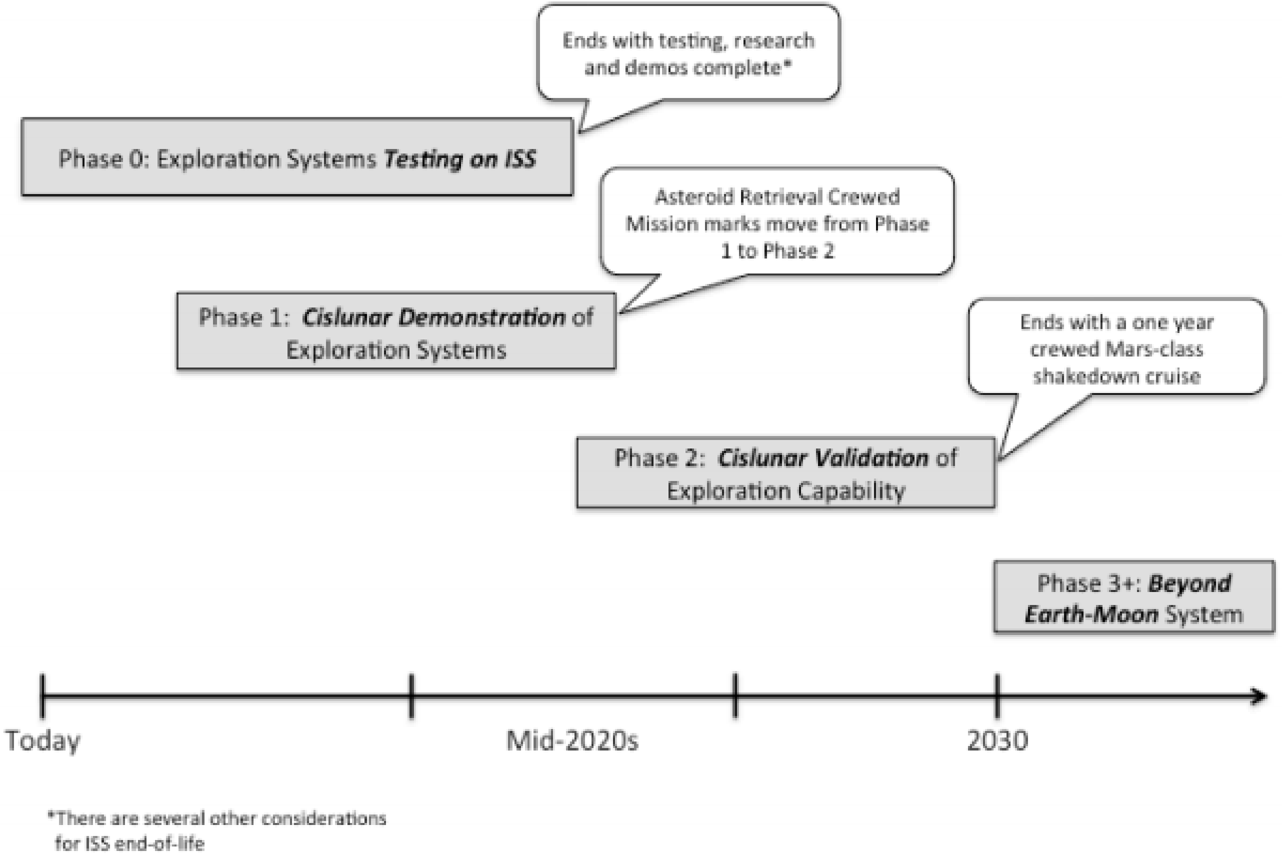
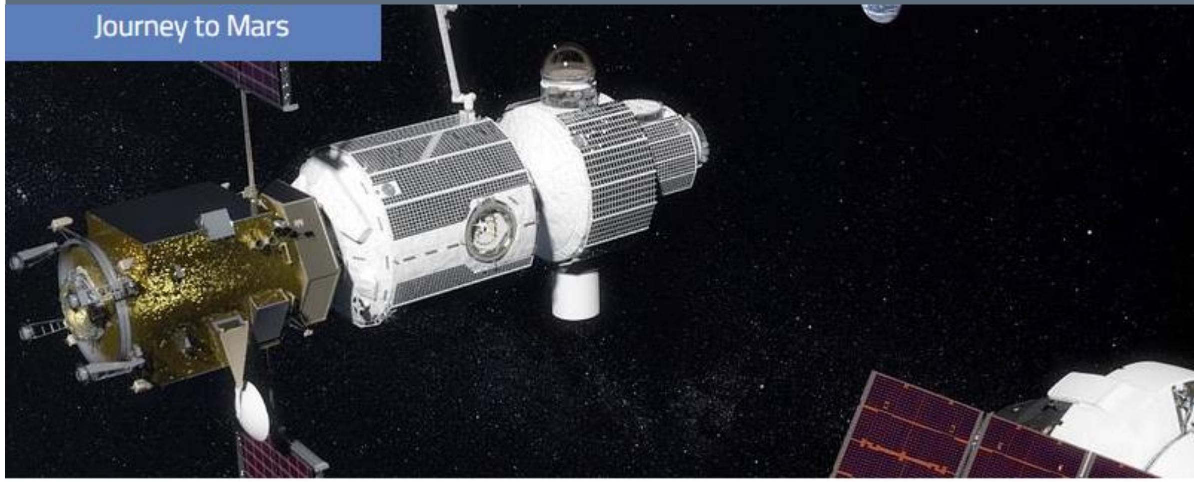


FIGURE 4.0-1 EXPLORATION PHASES

Human Exploration and Operations Exploration Objectives, 2016

Deep Space Gateway – crewed spaceport in lunar orbit – access lunar surface & deep space

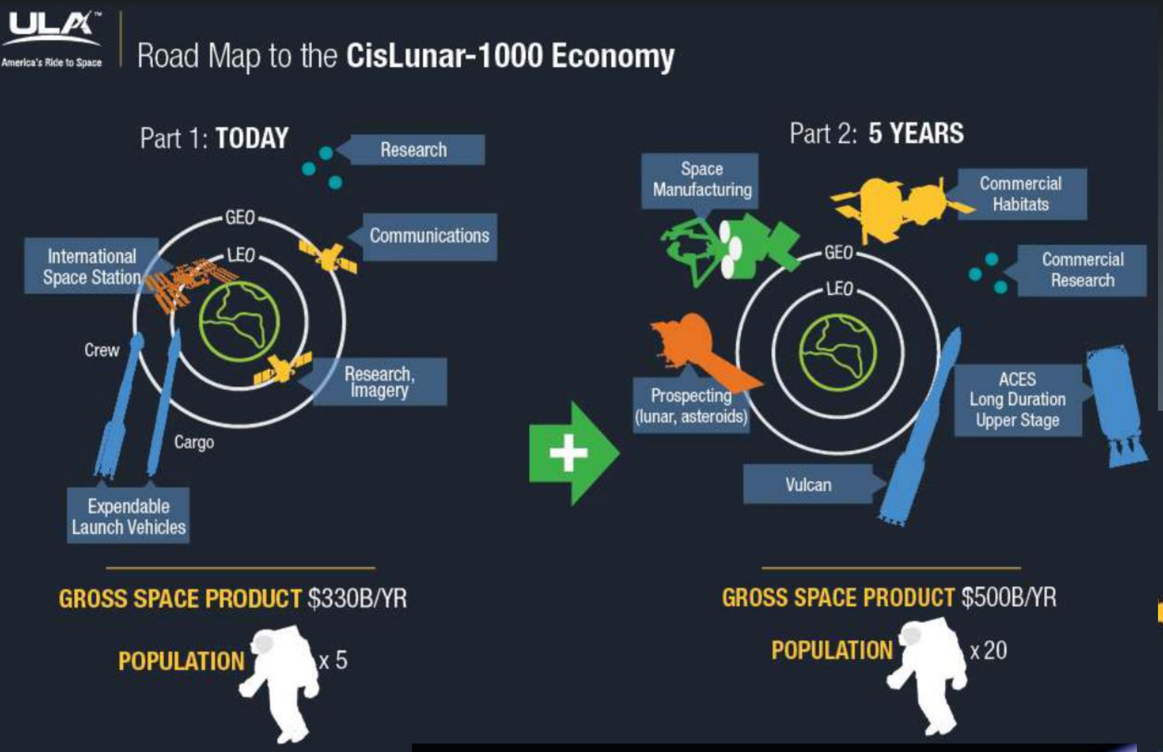
Deep Space Transport – reusable vehicle to travel to Mars and return to the gateway

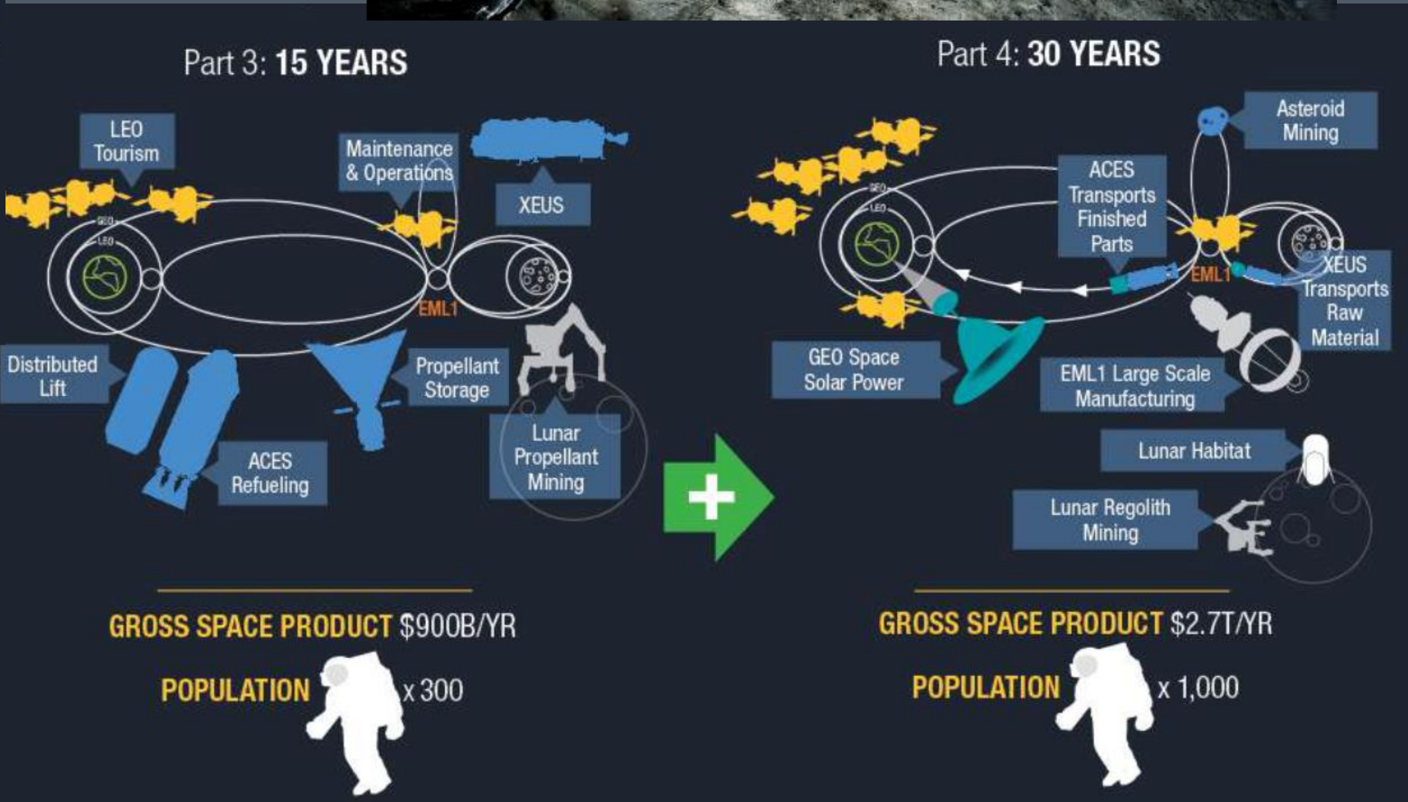


March 28, 2017

Deep Space Gateway to Open Opportunities for Distant Destinations

Commercial uses of Cislunar Space





ESA – Moon Village & Amazon Moon Deliveries

BEAM – Bigelow Expandable Activity Module

Space Farming = f (Plant/Microbial Biology & Engineering)

Research Issues

- Sensory mechanisms: Gravity sensing and response to mechanisms in cells, plants & microbes.
- Radiation effects on plants/microbes
- Plant/microbial growth under altered atmospheric pressures
- **Spaceflight syndromes**: Responses to integrated spaceflight environment, microbial ecosystems and environments, changes in virulence of pathogens.
- Food safety
- Plant – Microbe Interactions

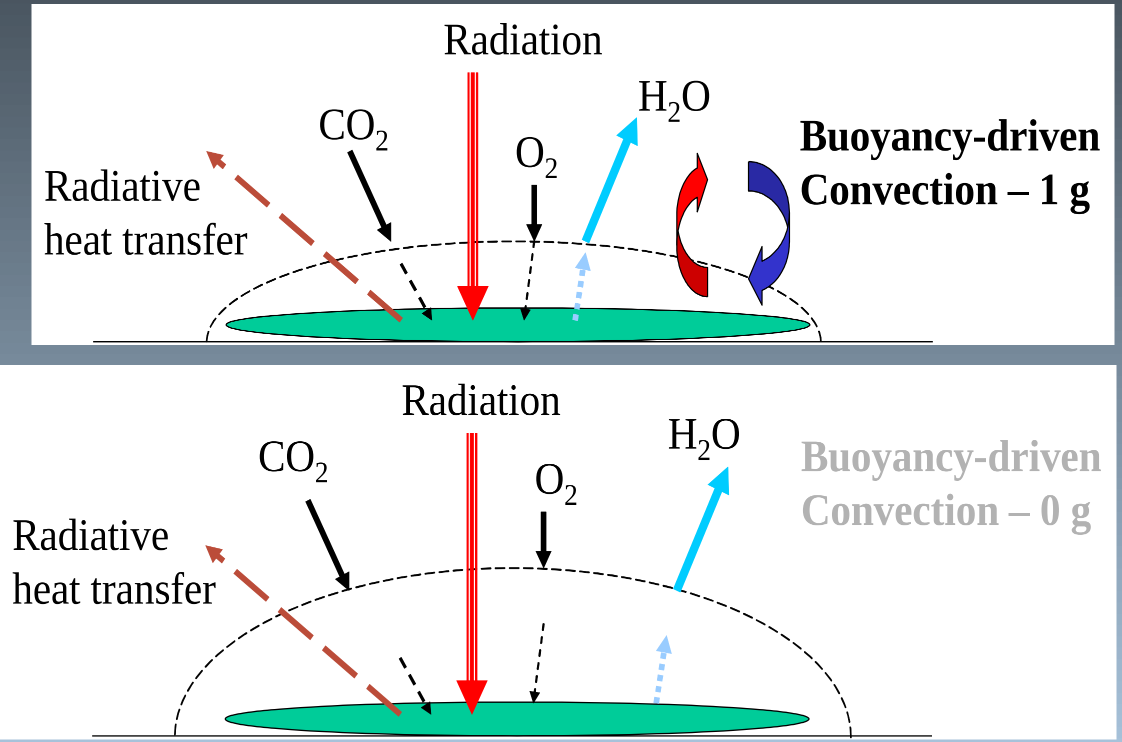
Hardware Issues

- **Performance**: Mitigate spaceflight syndromes for adequate plant growth
- Mass, power & volume restrictions
- Role in life support systems

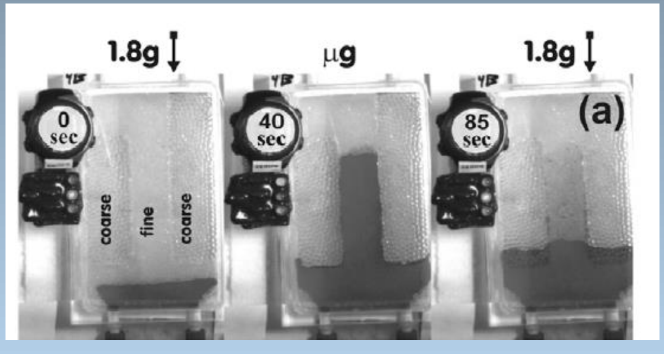
Space-Flight Environment

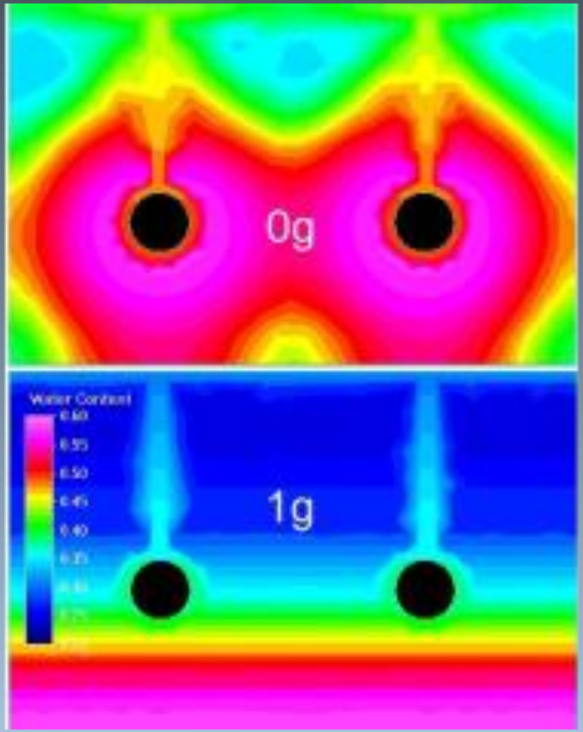
The absence of gravity induces physical effects that alter the microenvironment surrounding plants and their organs.

These effects include: increased boundary layers surrounding plant organs and the absence of convective mixing of atmospheric gases. In addition, altered behavior of liquids and gases is responsible for phase separation and for dominance of capillary forces in the absence of gravitational forces (moisture redistribution)



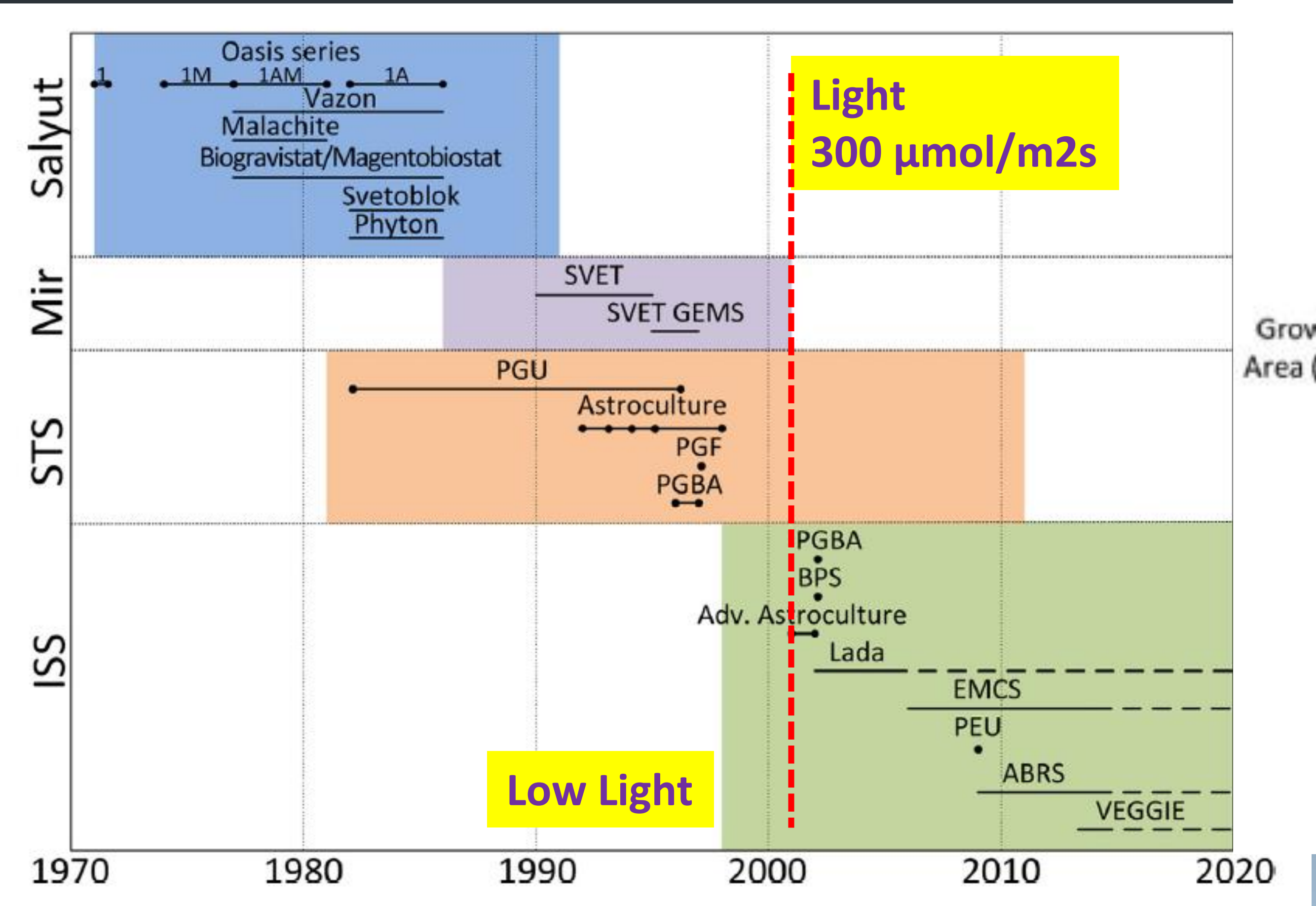
Monje et al. 2003

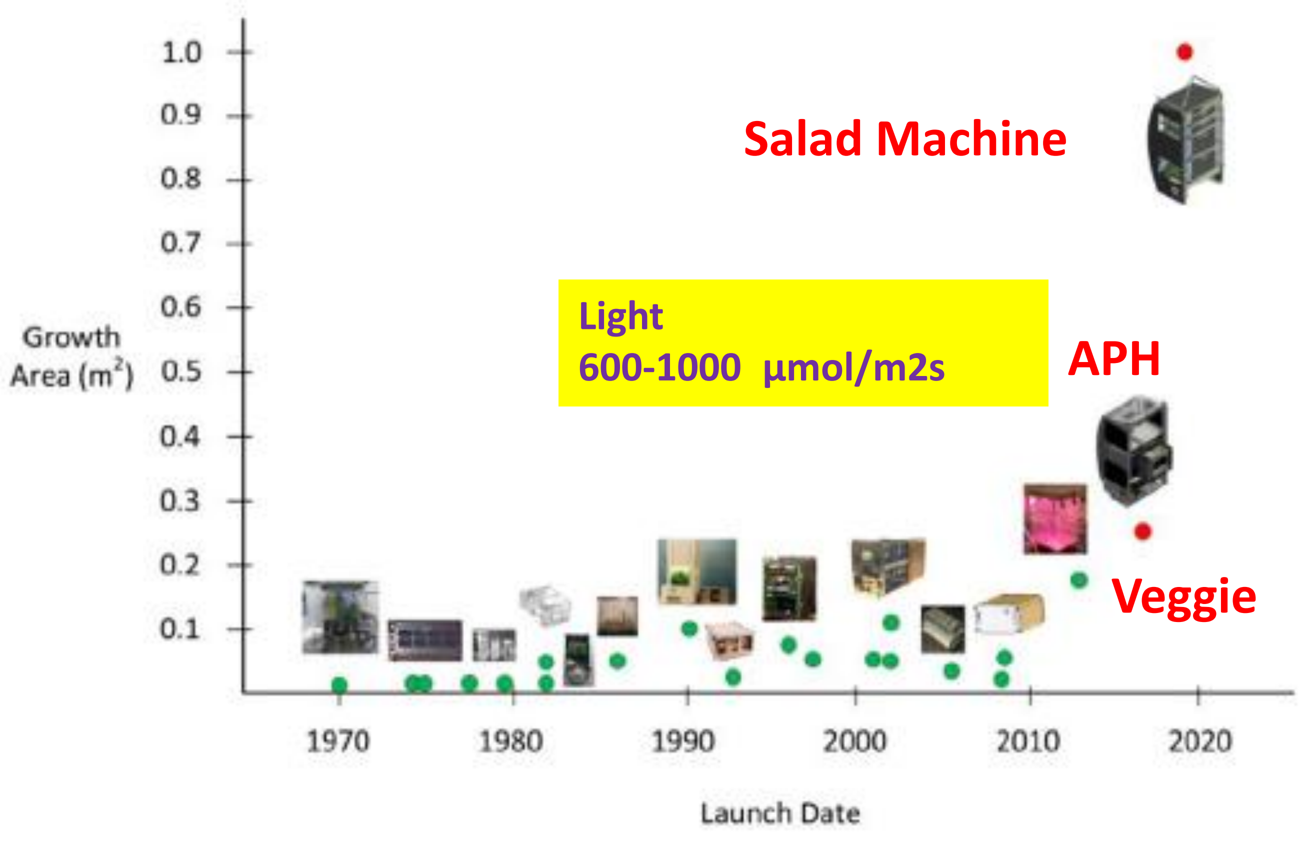




Jones and Or, 1998

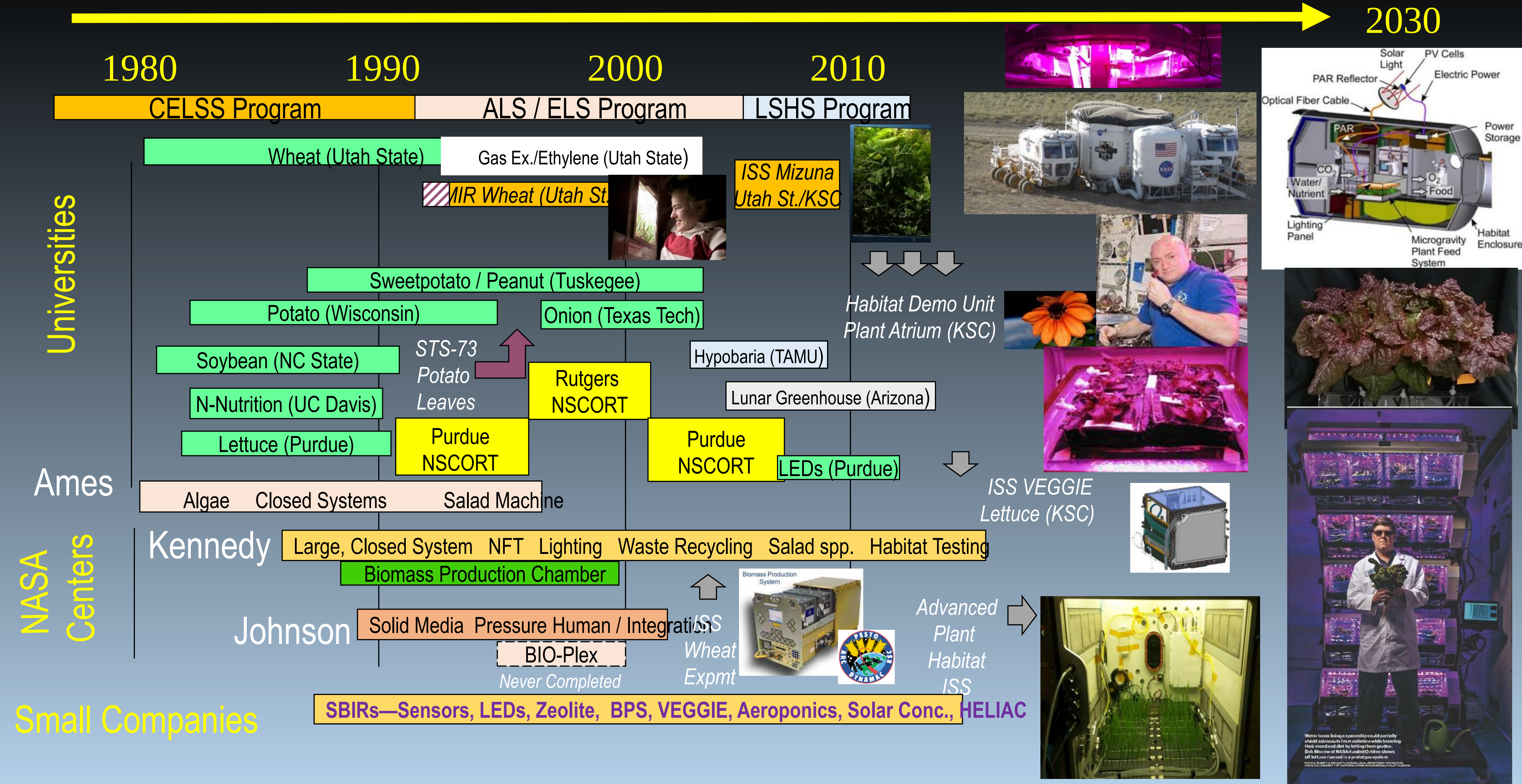
Plant Growth Systems





Zabel et al. Life Sci. Space Res. (2016)

NASA's Bioregenerative Life Support Testing



Recirculating Hydroponics with Crops– Record yields vs Field

Conserve Water & Nutrients
Eliminate Water Stress
Optimize Mineral Nutrition
Facilitate Harvesting
Will this work in partial g?

Wheeler et al., 1999. Acta Hort.

Cultivar Comparisons and Crop Breeding

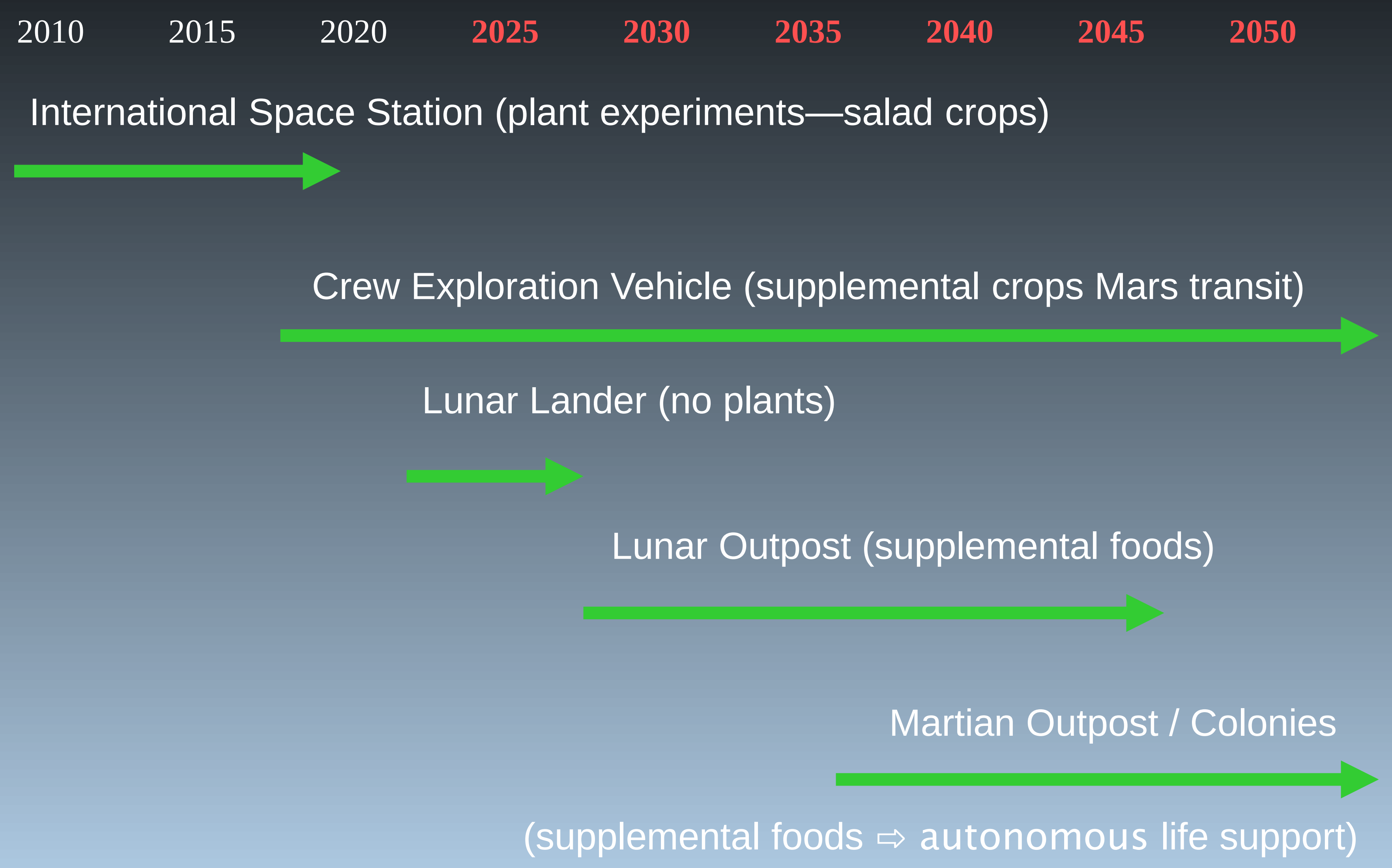
<u>Several Universities:</u>
Cultivar Comparisons
wheat, potato, soybean, lettuce, sweetpotato, tomato

←
<u>Utah State:</u>
Super Dwarf Wheat
Apogee Wheat
Perigee Wheat
Super Dwarf Rice

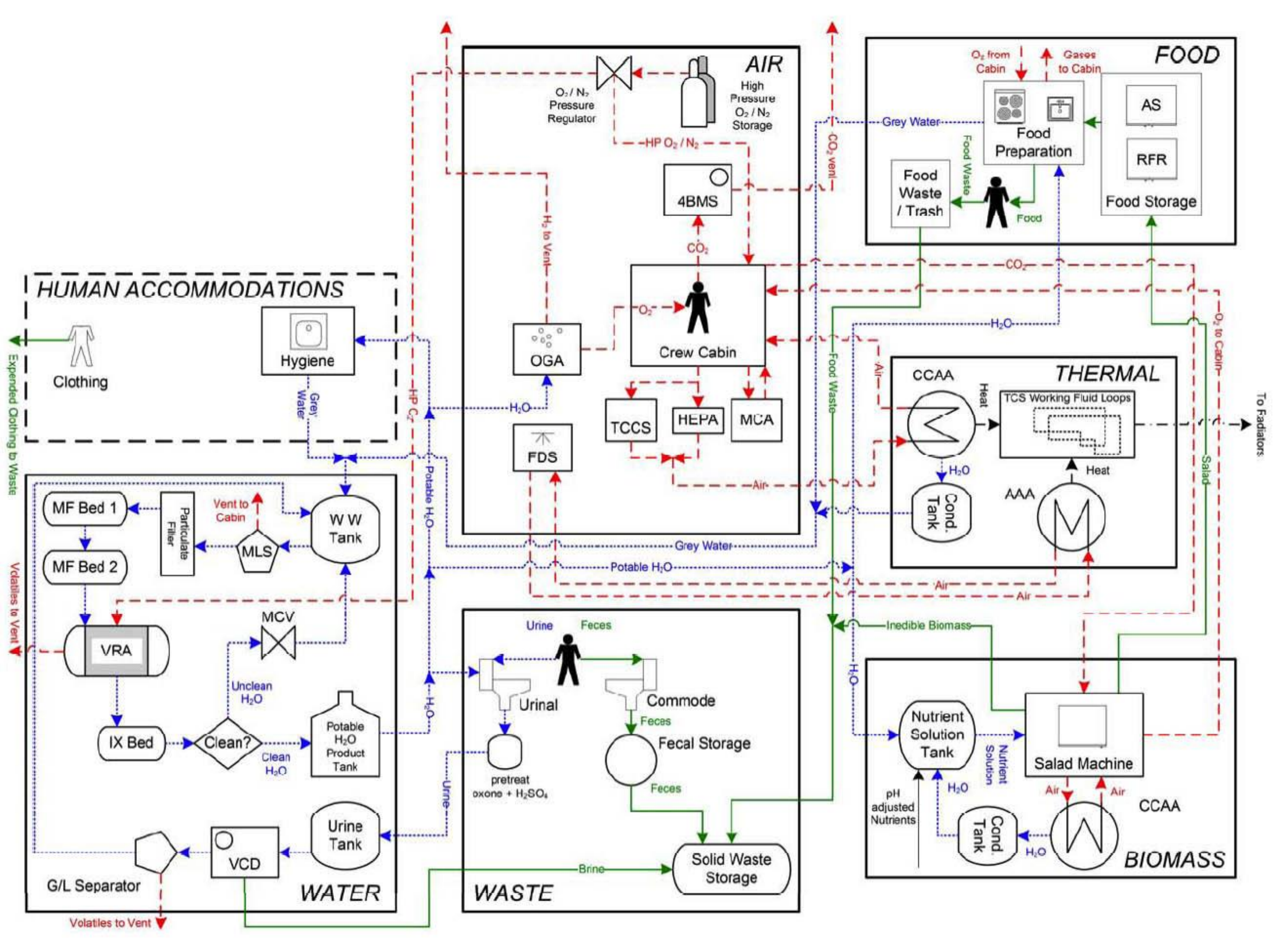
Dwarf Pepper ↑ and Tomato ↓

<u>Tuskegee:</u>
ASP GM-Sweetpotato
←

Plants for Future Space Missions



Bioregenerative Life Support

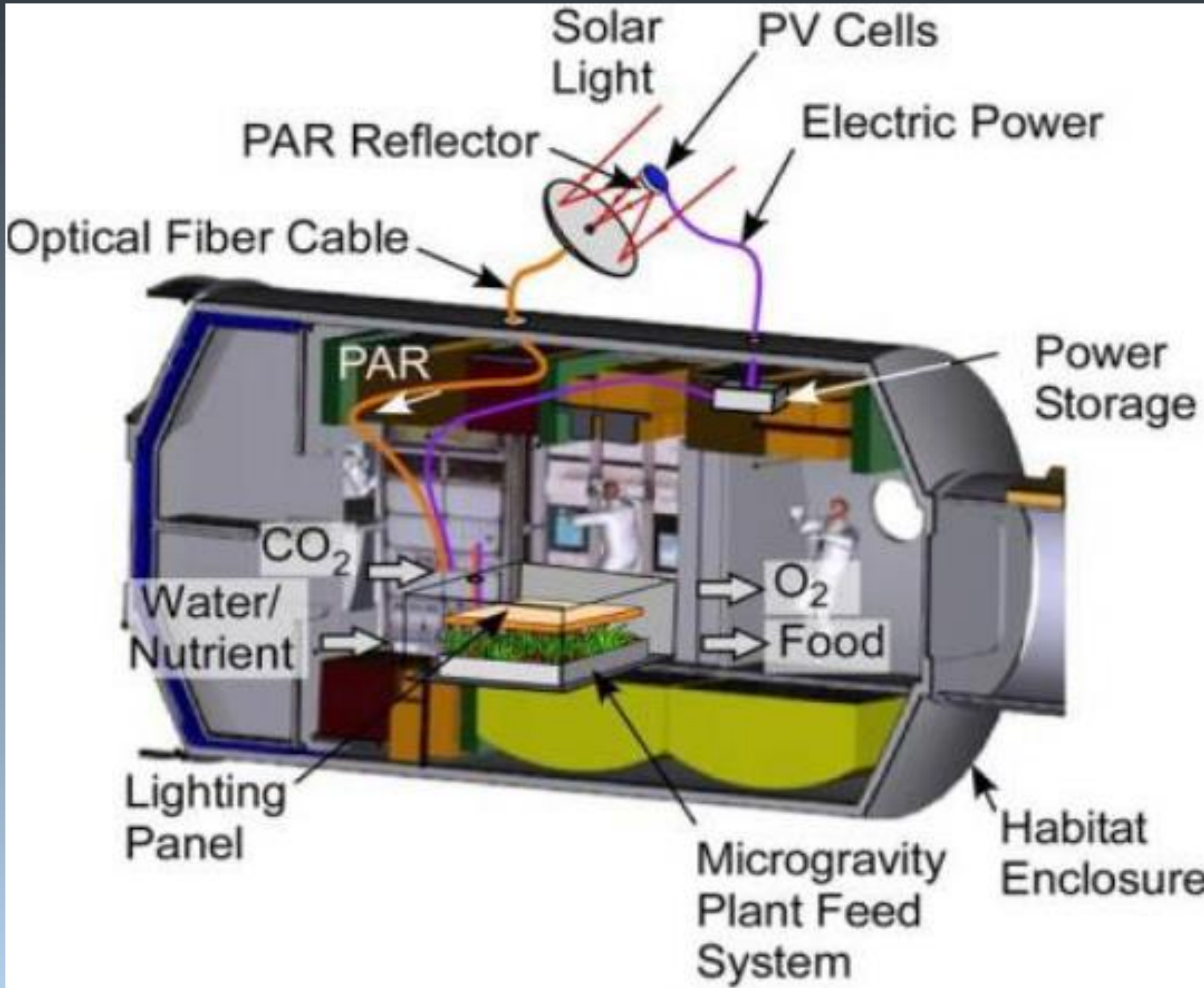


Integrate physico-chemical and plant-based life support systems

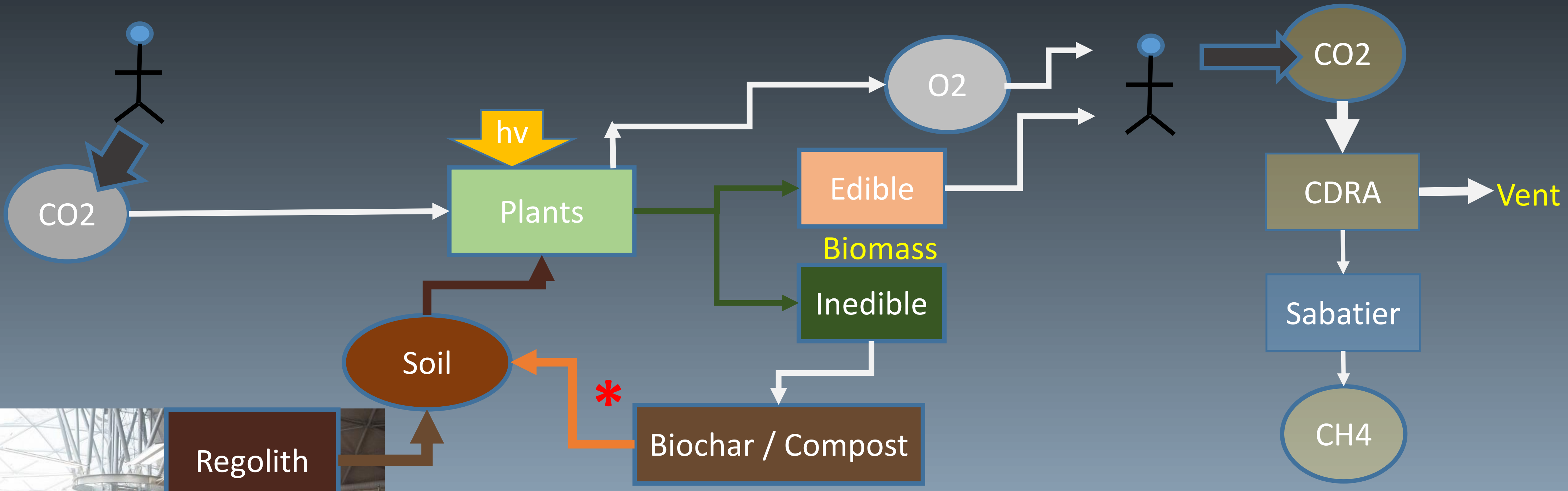
Salad Machine – Transit / Orbit

- Scale – Expand from Experimental to Production
  - 150 g/d = daily: 25 g salad for Crew of 6
  - 1 m^2 Planting area
- Performance criteria:
  - Productivity – maximize
  - Consistency – robust, repeatable
  - Crew Time – minimal
- Spacecraft
  - Cabin air – CO_2, VOCs
  - Limited Power & Volume
  - Water load to ECLSS
  - Microgravity Effects

Nakamura, Monje & Bugbee AAIA 2013



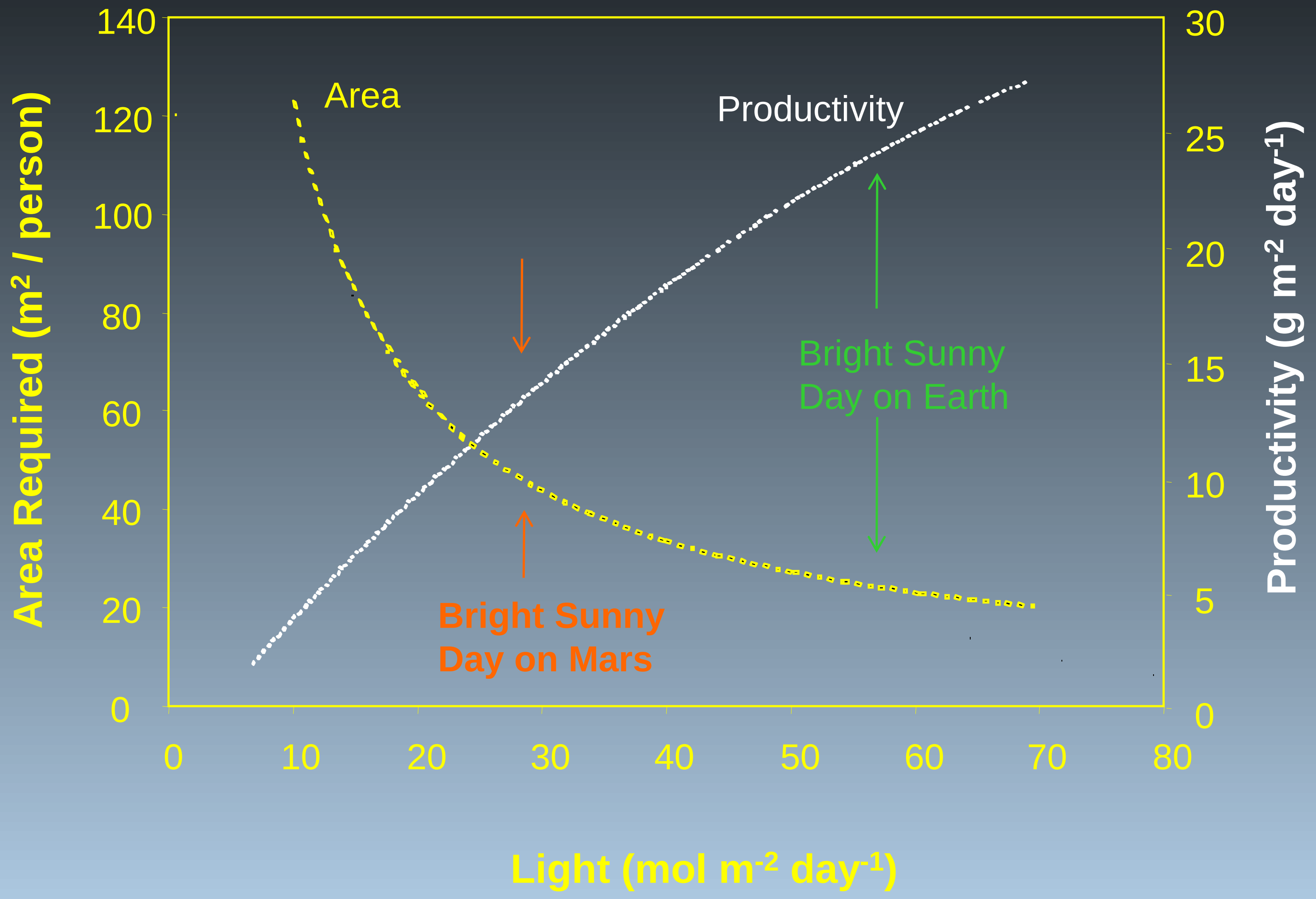
Make Soil on Surface Systems



*** Soil Amendments ISRU**

Questions?

Light, Productivity, and Crop Area Requirements



NASA's Biomass Production Chamber (BPC)