Plants for Space Travel

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Plants Beyond Limits
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Human Life Support Requirements:

Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%
TOTAL	**31.0 kg**	

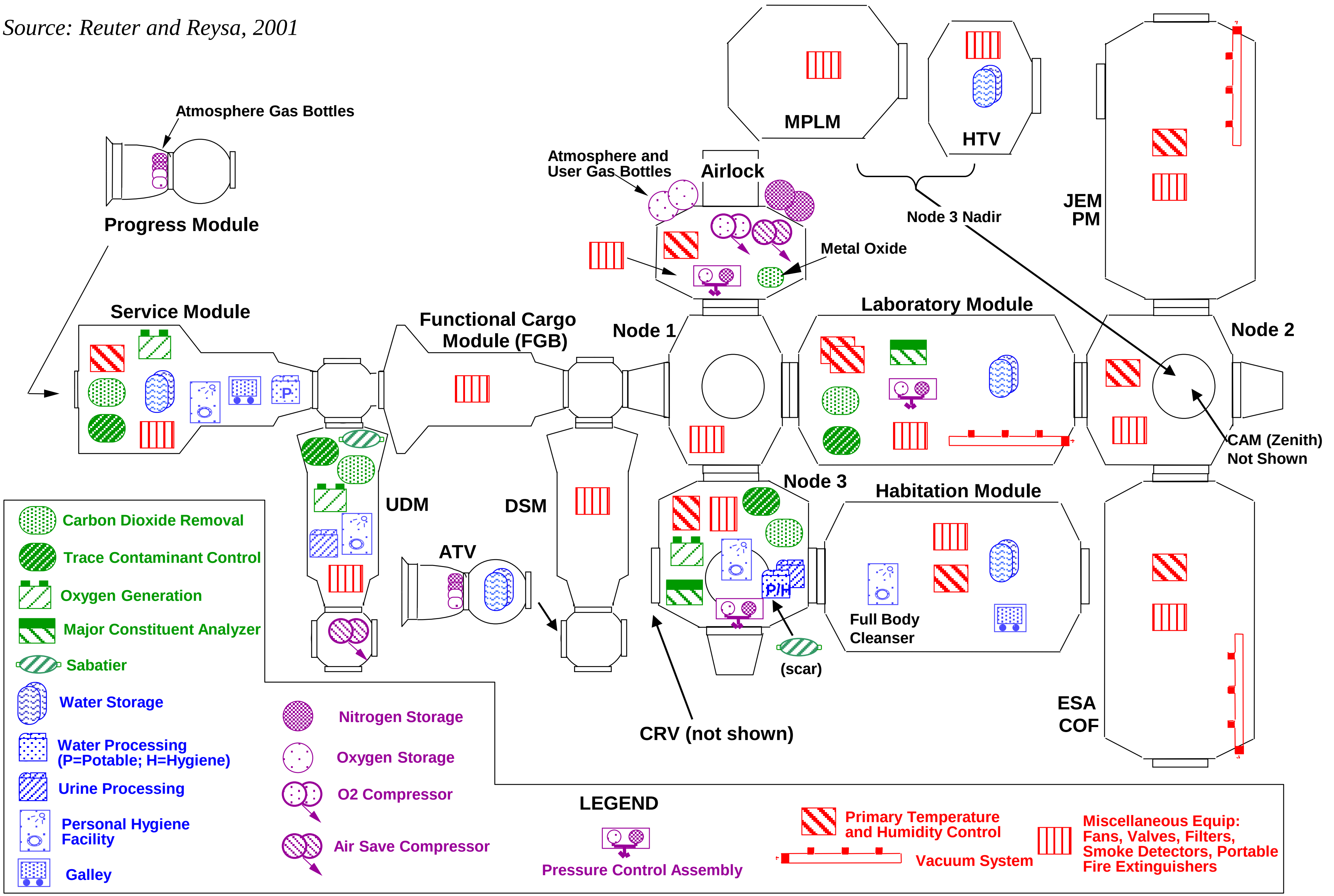
Outputs

	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)
TOTAL	**31.0 kg**	

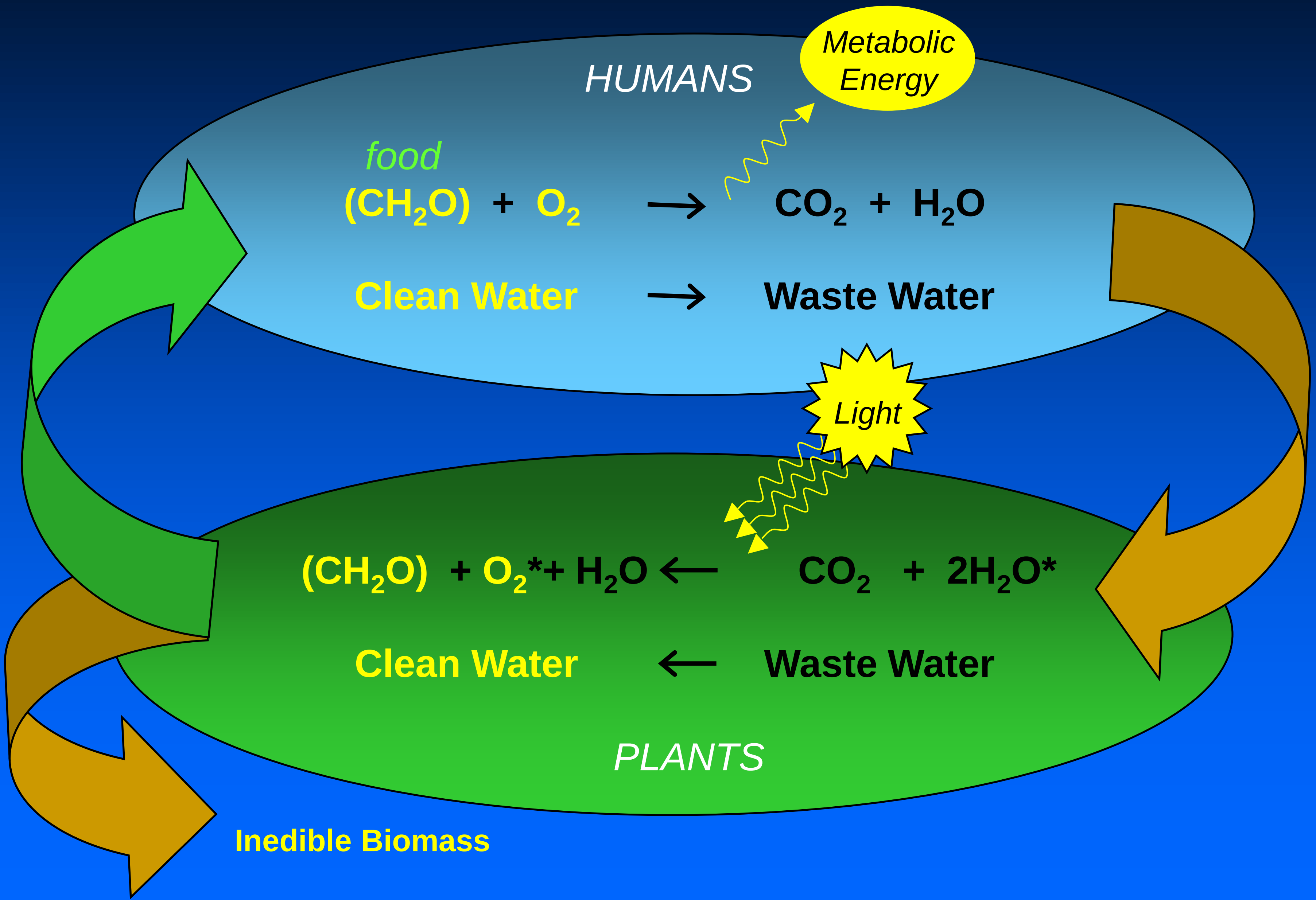
Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document
Food assumed to be dry except for chemically-bound water.

International Space Station Life Support Systems

Source: Reuter and Reysa, 2001



Plants for "Bioregenerative" Life Support

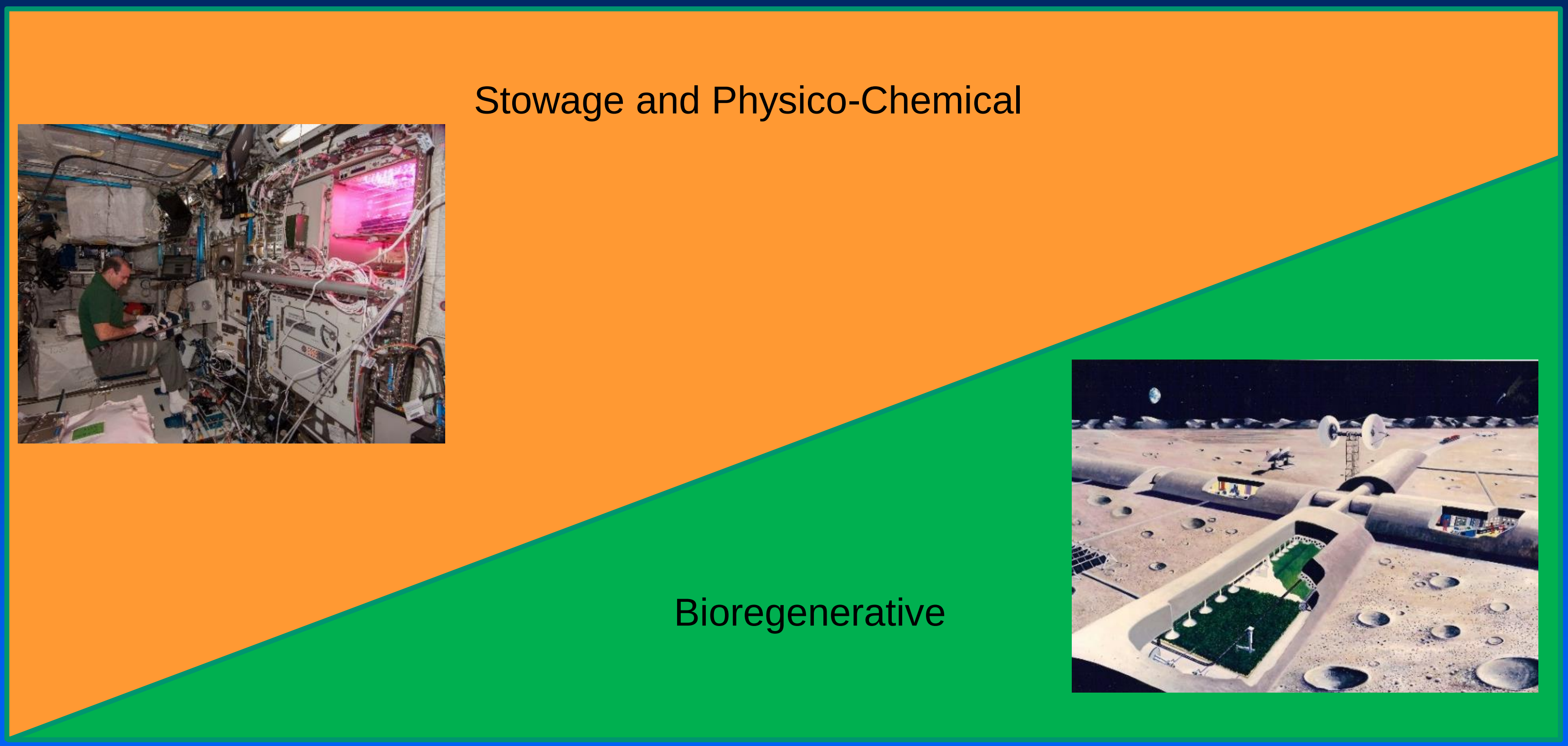


Life Support Options for Different Missions

Short Duration Missions

Longer Durations

Autonomous Colonies



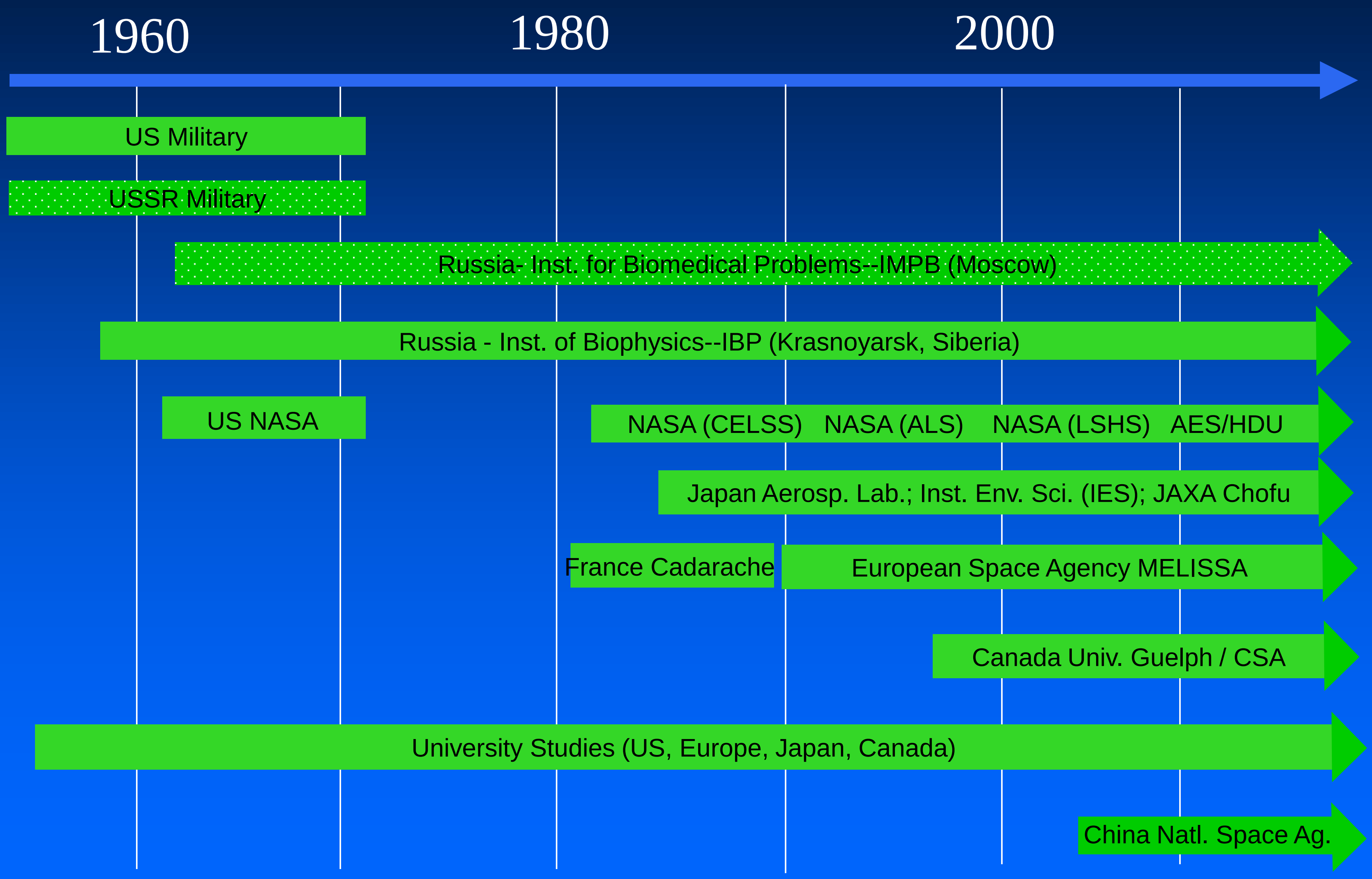
Role of Plants:

Supplemental Food
0.5 – 5 m^2 plant area

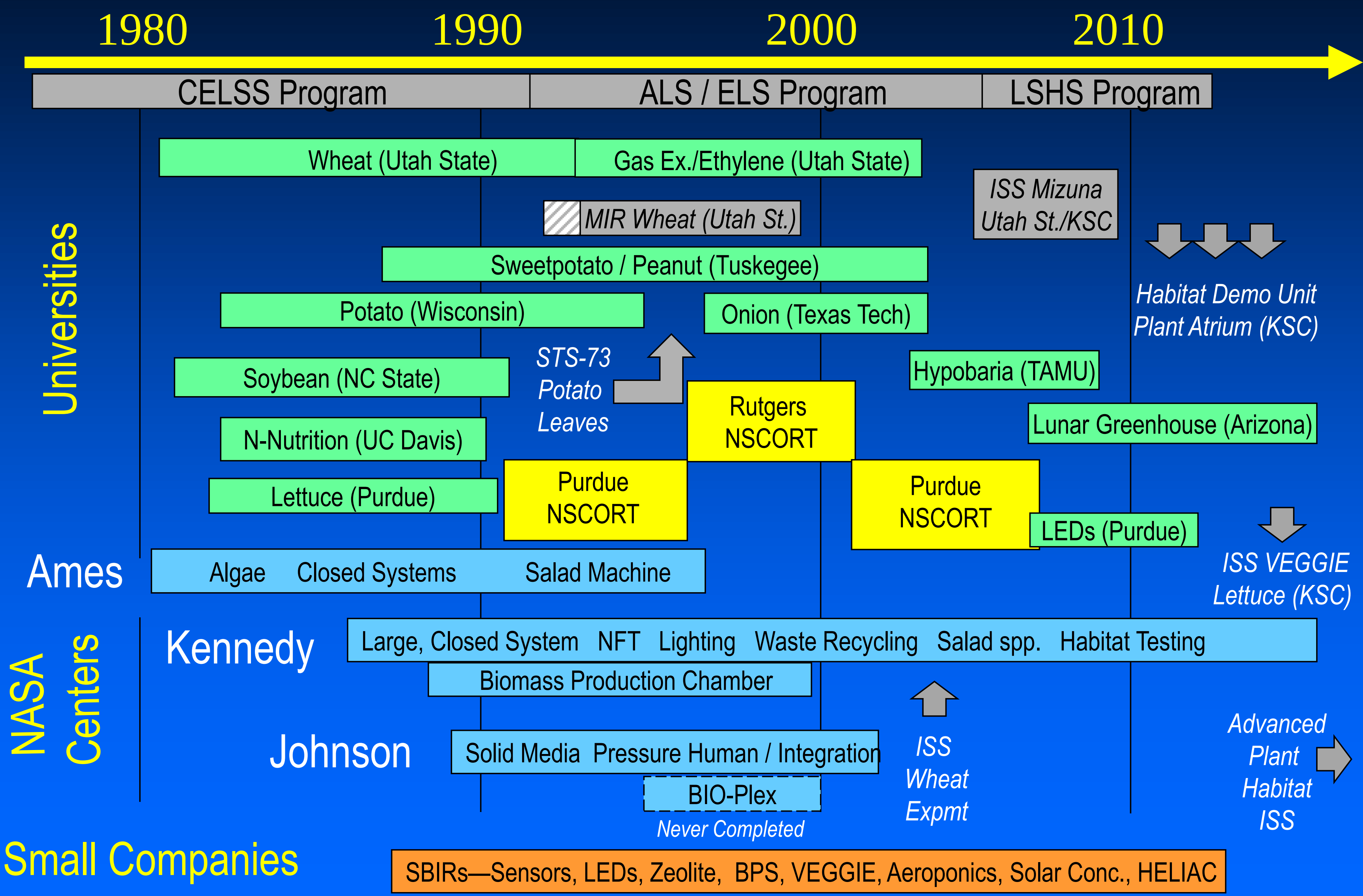
“More” Food, Partial O_2, CO_2 removal
5 – 25 m^2 plant area

Most Food, All O_2, All CO_2 removal
25 – 50 m^2 plant area

Bioregenerative Life Support Testing Around the World



NASA's Bioregenerative Life Support Testing



Crop Considerations for Space

- High yielding and nutritious (CHO, protein, fat)
  - Secondary Metabolites—e.g., antioxidants, lutein, zeaxanthin
- High harvest index (edible / total biomass)
- Dwarf or low growing types
- Environmental considerations
  - lighting, temperature, mineral nutrition, CO_2
- Horticultural considerations
  - planting, watering, harvesting, pollination, propagation
- Processing requirements

Some Crops for Life Support

Hoff, Howe, and Mitchell (NASA)[a]	Salisbury and Clark (NASA)[b]	Crops Used in BIOS-3 (Russia)[c]	Tako et al CEEF (Japan)[d]	Waters et al.[e] (ESA / Canada)
Wheat	Wheat	Wheat	Rice	Lettuce
Potato	Rice	Potato	Soybean	Wheat
Soybean	Sweetpotato	Carrot	Peanut	Potato
Rice	Broccoli	Radish	Sweetpotato	Sweetpotato
Peanut	Kale	Beet	Sugar Beet	Rice
Dry Bean	Lettuce	Nut Sedge	Carrot	Bean
Tomato	Carrot	Onion	Tomato	Beet
Carrot	Canola	Cabbage	Spinach	Cabbage
Chard	Soybean	Tomato	Shungiku	Broccoli
Cabbage	Peanut	Pea	Chinese Cabbage	Cauliflower
	Chickpea	Dill	Pea	Carrot
	Lentil	Cucumber	Onion/Leek	Kale
	Tomato	Salad spp.	Komatsuna	Onion
	Onion		Pepper	
	Chili Pepper			

[a] *Hoff, Howe, and Mitchell (1982);* [b] *Salisbury and Clark (1996);* [c] *Gitelson and Okladnikov (1994).*
[d] *Tako et al. (2010);* [e] *Waters et al. (2002)*

Targeted Crop Selection and Breeding for Space at Utah State University

Selection of Existing Rice Genotypes

Targeted Wheat Breeding

'Apogee' Wheat 'Perigee' Wheat

Genetic Engineering Tools

Early Flowering and Fruit Set

No Dormancy Requirements

Overexpression of FT flowering gene in plums (ARS researchers) resulted in dwarf growth habit and early flowering

Water and Nutrients for Growing Crops

Recirculating Hydroponics

Conserve Water & Nutrients
Eliminate Water Stress
Optimize Mineral Nutrition
Facilitate Harvesting

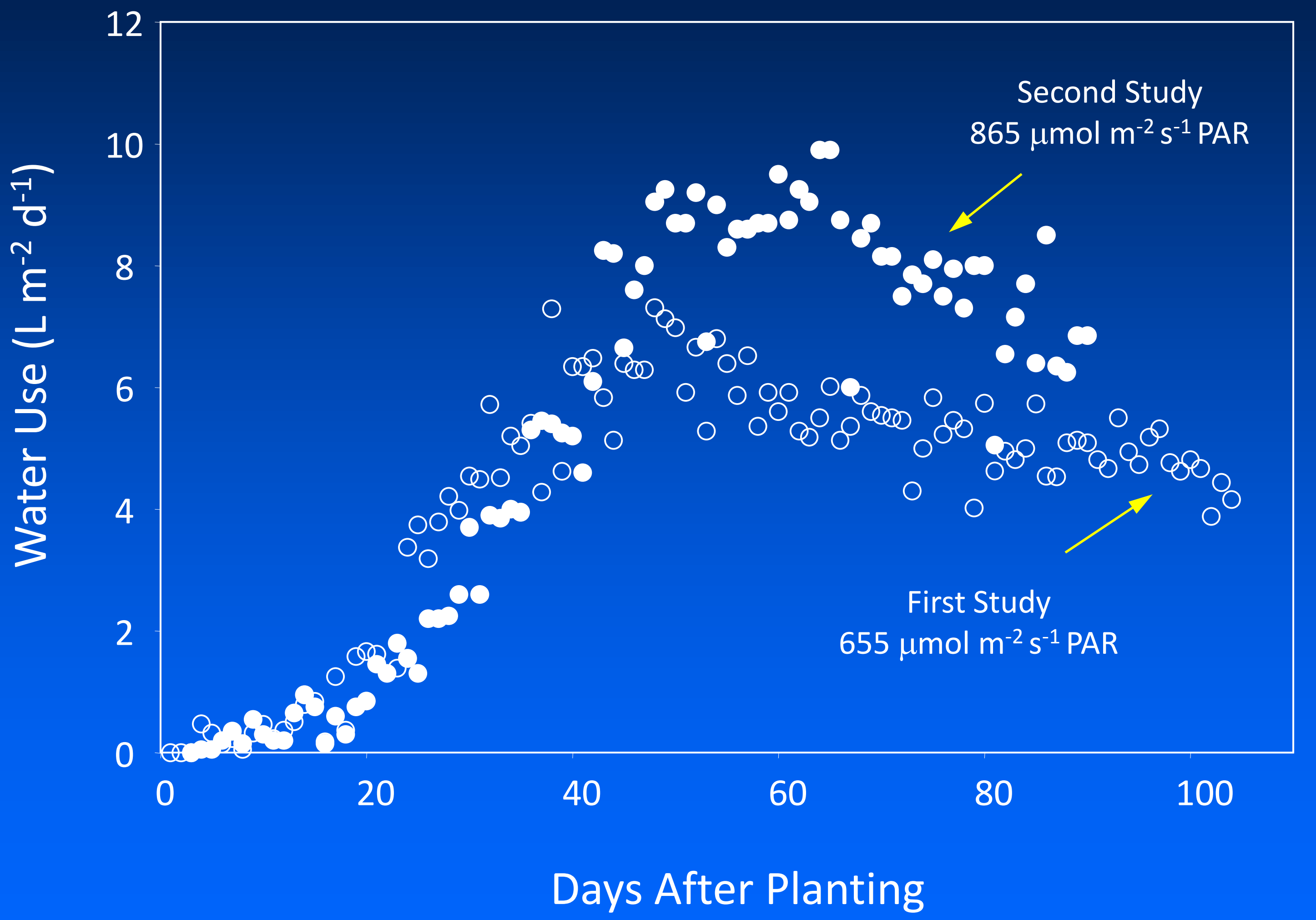
Wheeler et al., 1999. Acta Hort.

Root Zone Crops in Nutrient Film Technique (NFT)

Wheeler et al., 1990. Amer. Potato J. 67:177-187; Mackowiak et al. 1998. HortScience 33:650-651

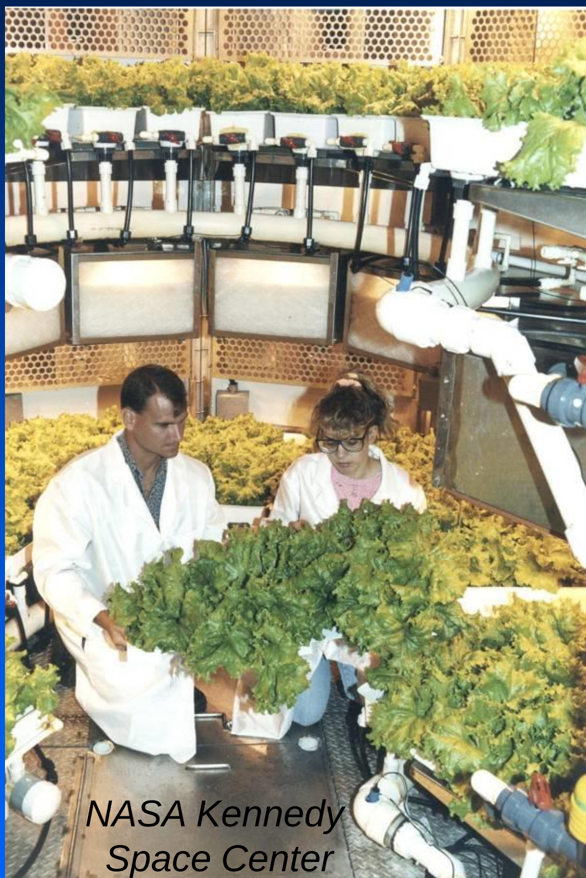
Fig. 7

Evapotranspiration from Plant Stand (potato)



Wheeler. 2006. Potato Research 49:67-90.

High Yields from NASA Sponsored Studies


NASA Kennedy Space Center

Wheat - 3-4 x World Record
Potato - 2 x World Record
Lettuce-Exceeded Commercial Yield Models

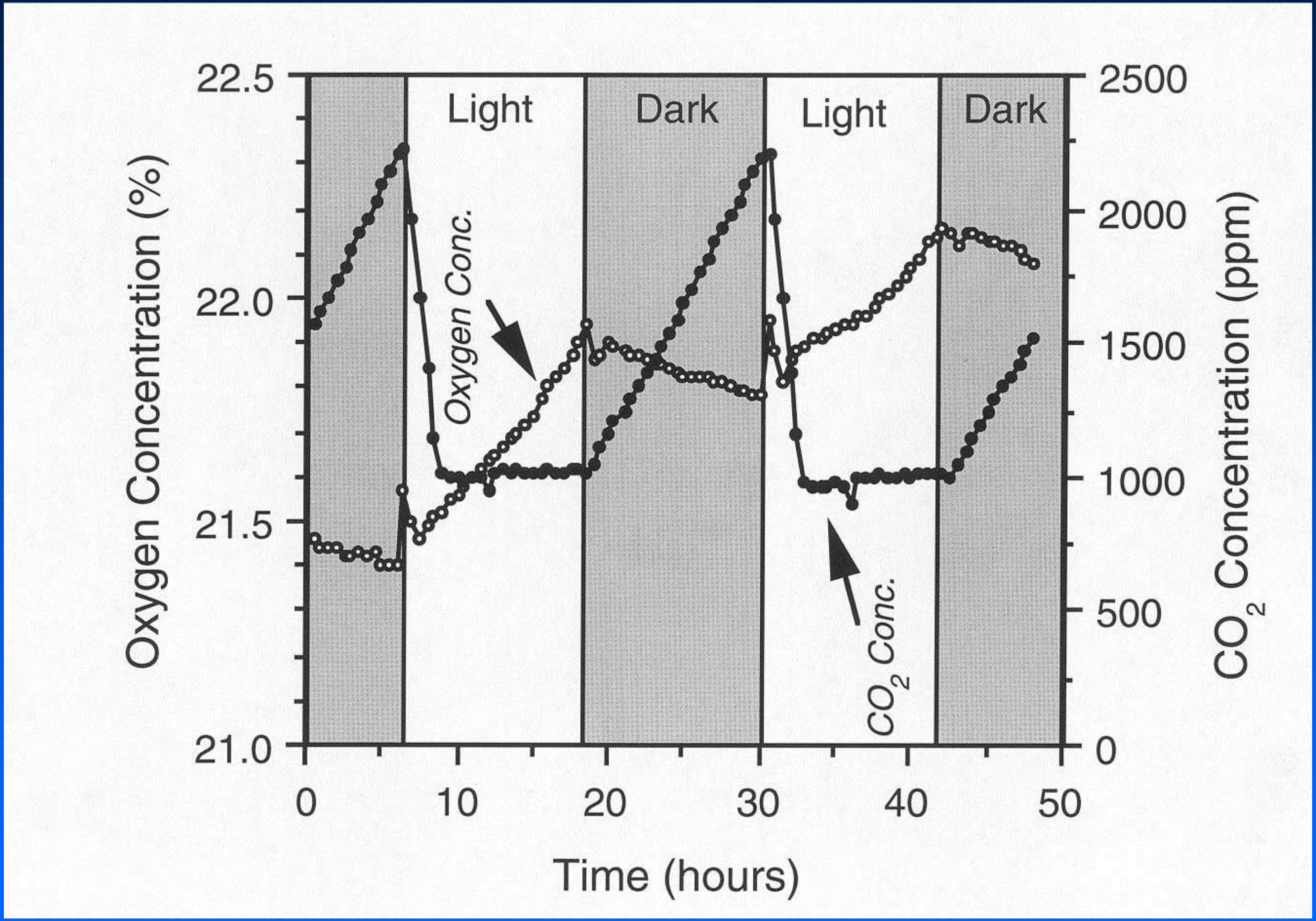
Wisconsin Biotron


Utah State Univ.

Bubgee, B.G. and F.B. Salisbury. 1988. Plant Physiol. 88:869-878.
Wheeler, R.M., T.W. Tibbitts, A.H. Fitzpatrick. 1991. Crop Science 31:1209-1213.

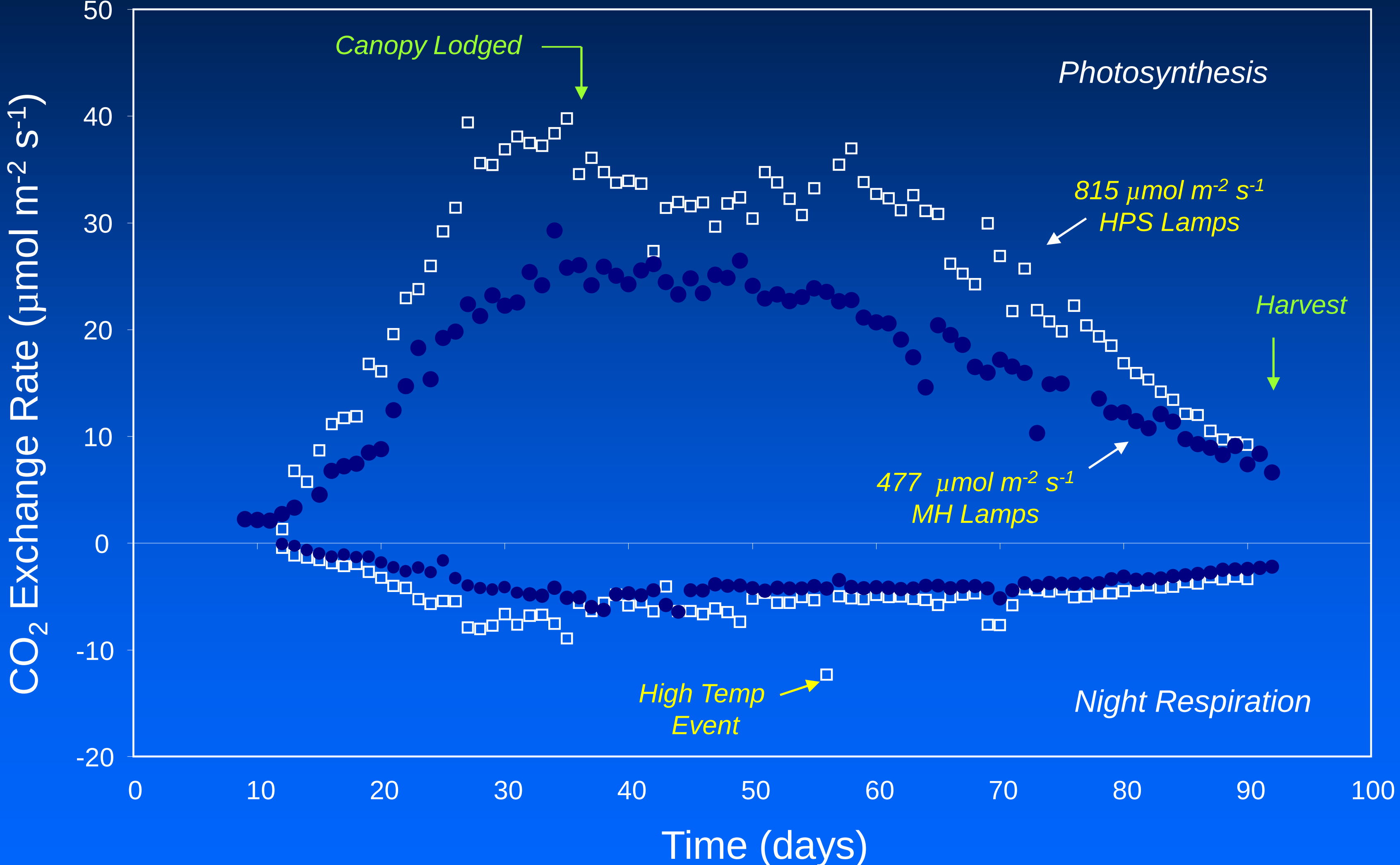
Canopy CO_2 Uptake / O_2 Production

(20 m^2 Soybean Stand)



Wheeler. 1996. In: H. Suge (ed.) Plants in Space Biology.

CO_2 Exchange Rates of Soybean Stands



Wheeler et al., 2004. EcoEngineering.

Ethylene Gas in Closed Systems

Epinastic
Wheat Leaves
at ~120 ppb

Epinastic
Potato Leaves
at ~40 ppb

Wheeler et al., 2004 HortScience

NASA’s Biomass Production Chamber (BPC)

Early Vertical Agriculture !

20 m^2 growing area; 113 m^3 vol.; 96 400-W HPS Lamps; 400 m^3 min^{-1} air circulation; two 52-kW chillers

NASA's Biomass Production Chamber (BPC)

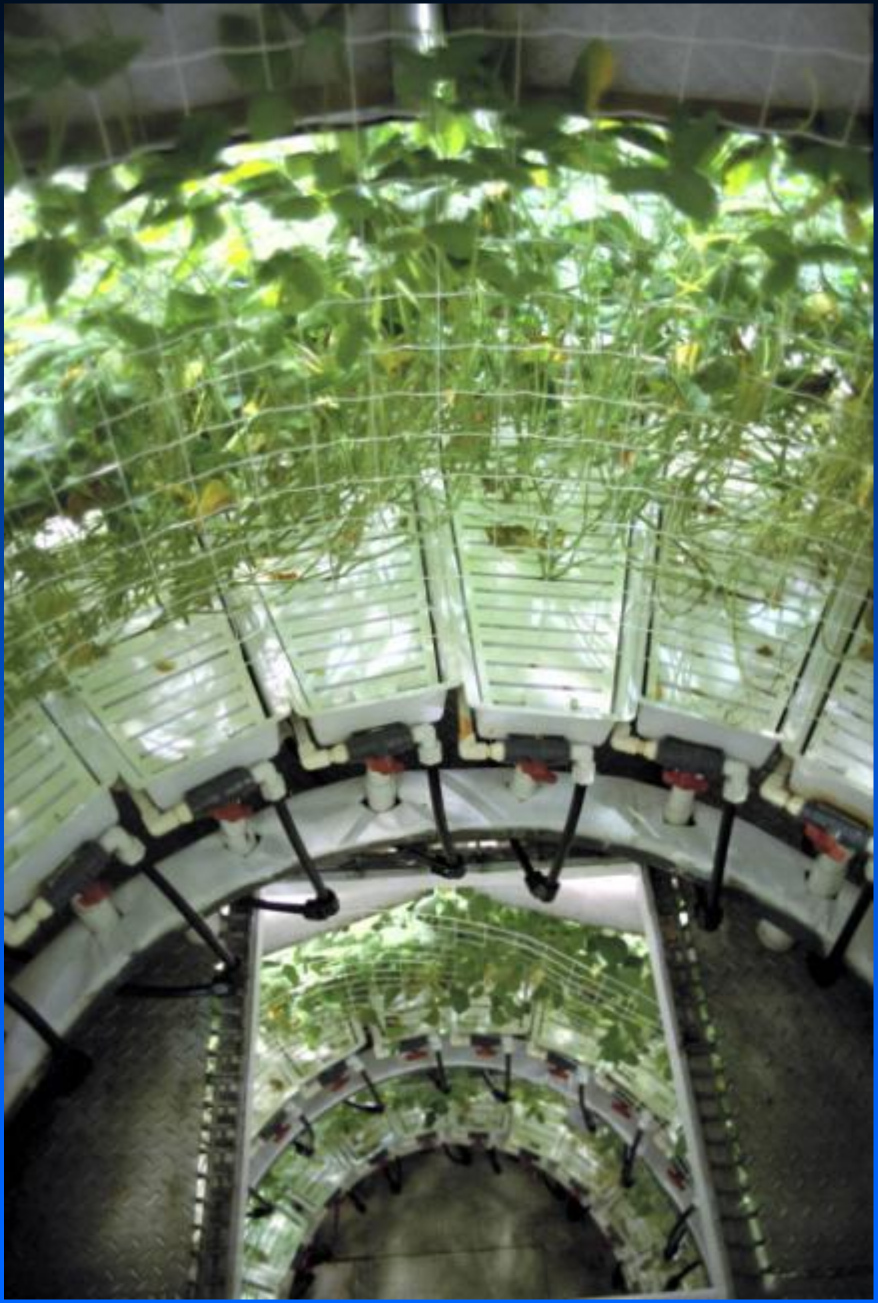
…an early example of a Vertical Agriculture Systems

Wheat

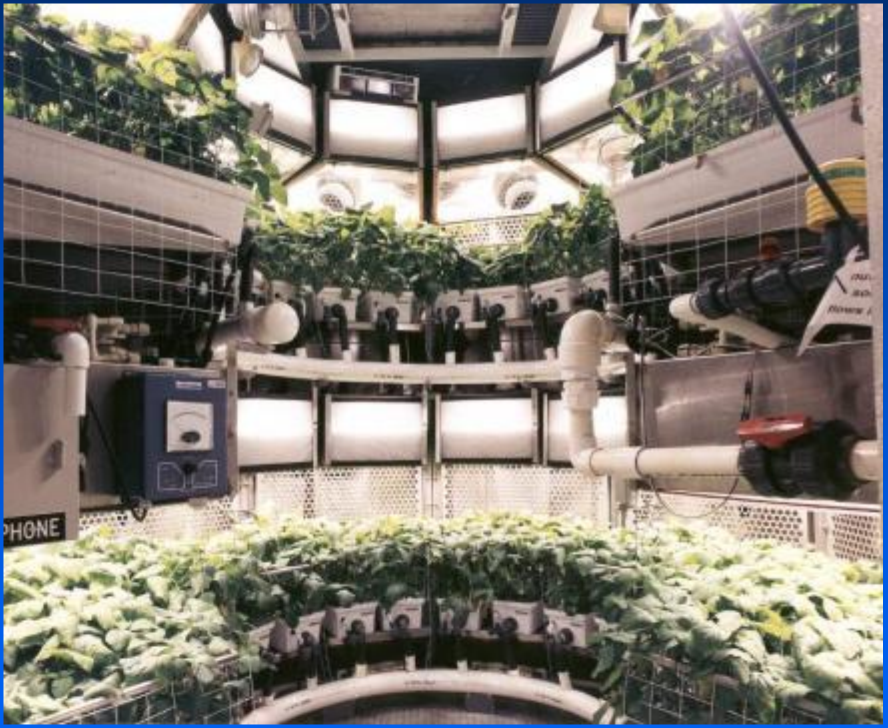
(Triticum aestivum)

planting

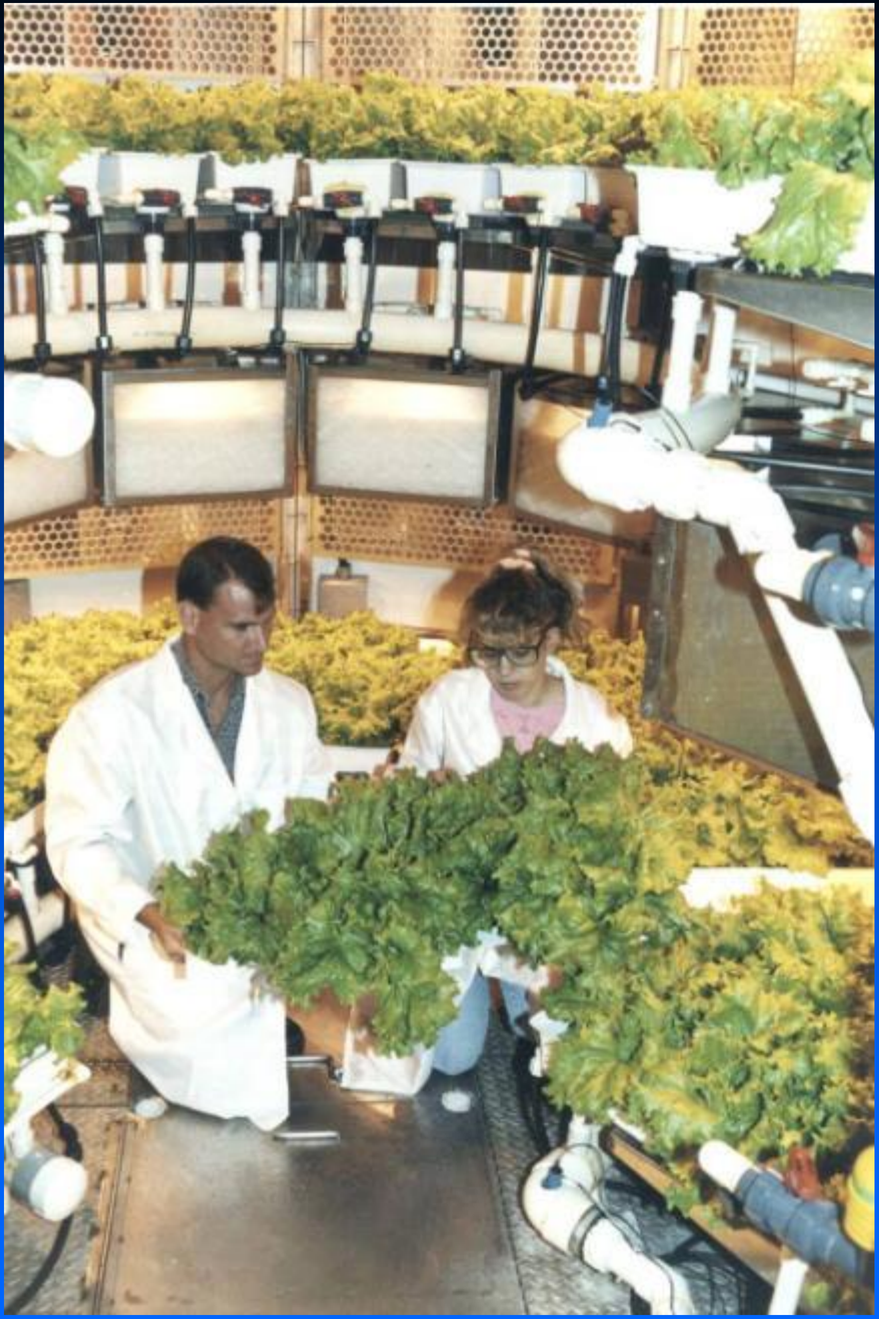
harvest



Soybean
(Glycine max)



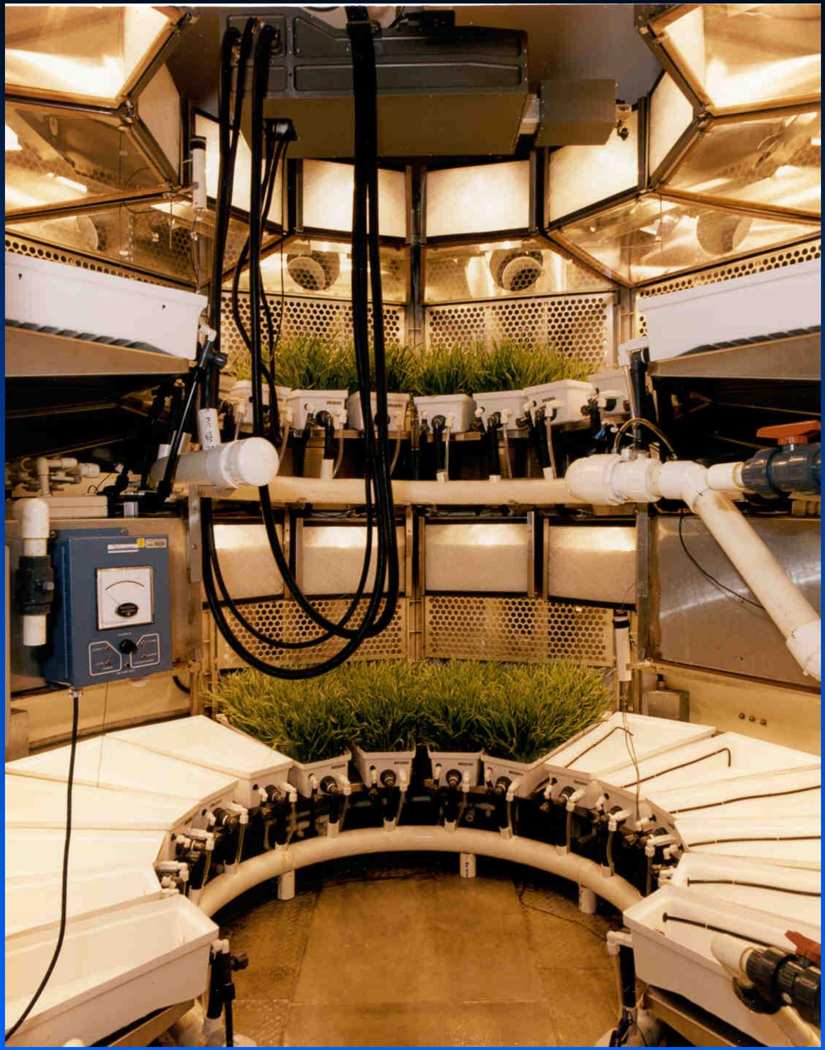
Lettuce
(Lactuca sativa)



Potato

(Solanum tuberosum)

Automation Technologies for CEA



ALSARM Robot in NASA Biomass Production Chamber

Electric Lamp Options for Lighting

Lamp Type	*Conversion* Efficiency*	*Lamp Life* (hrs)*	*Spectrum*
• Incandescent/Tungsten**	5-10%	2000	Intermd.
• Xenon	5-10%	2000	Broad
• Fluorescent***	20%	5,000-20,000	Broad
• Metal Halide	25%	20,000	Broad
• High Pressure Sodium	30-35%	25,000	Intermd.
• Low Pressure Sodium	35%	25,000	Narrow
• Microwave / RF Sulfur	35-40%+	?	Broad
• LEDs (red and blue)****	>40%	50,000 ?	Narrow

* *Approximate values.*

** *Tungsten halogen lamps have broader spectrum.*

*** *For VHO lamps; lower power lamps with electronic ballasts last up to ~20,000 hrs.*

**** *State-of-Art Blue and Red LEDs most efficient.*

LED Studies

Red...photosynthesis
Blue...photomorphogenesis
Green...human vision

Goins et al., 1997. J. Ex. Bot.; Kim et al. 2004 Ann. Bot.

North American Patent for Using LEDs to Grow Plants Developed with NASA Funding at University of Wisconsin – WCSAR

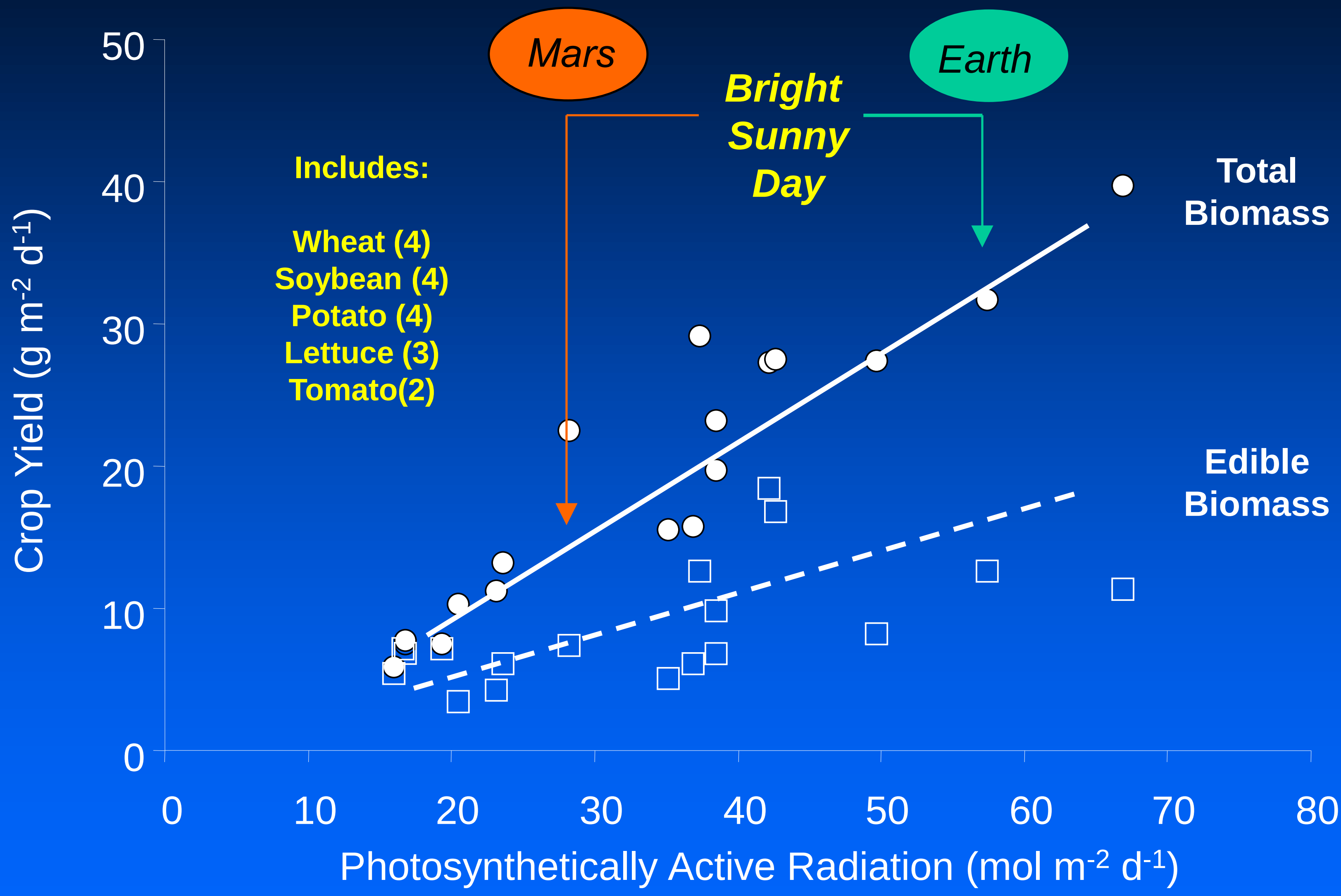
Solar Collector / Fiber Optics For Plant Lighting

2 m^2 of collectors on solar tracking drive (NASA KSC)

Up to 400 W light delivered to chamber (40-50% of incident light)
Takashi Nakamura, Physical Sciences Inc.

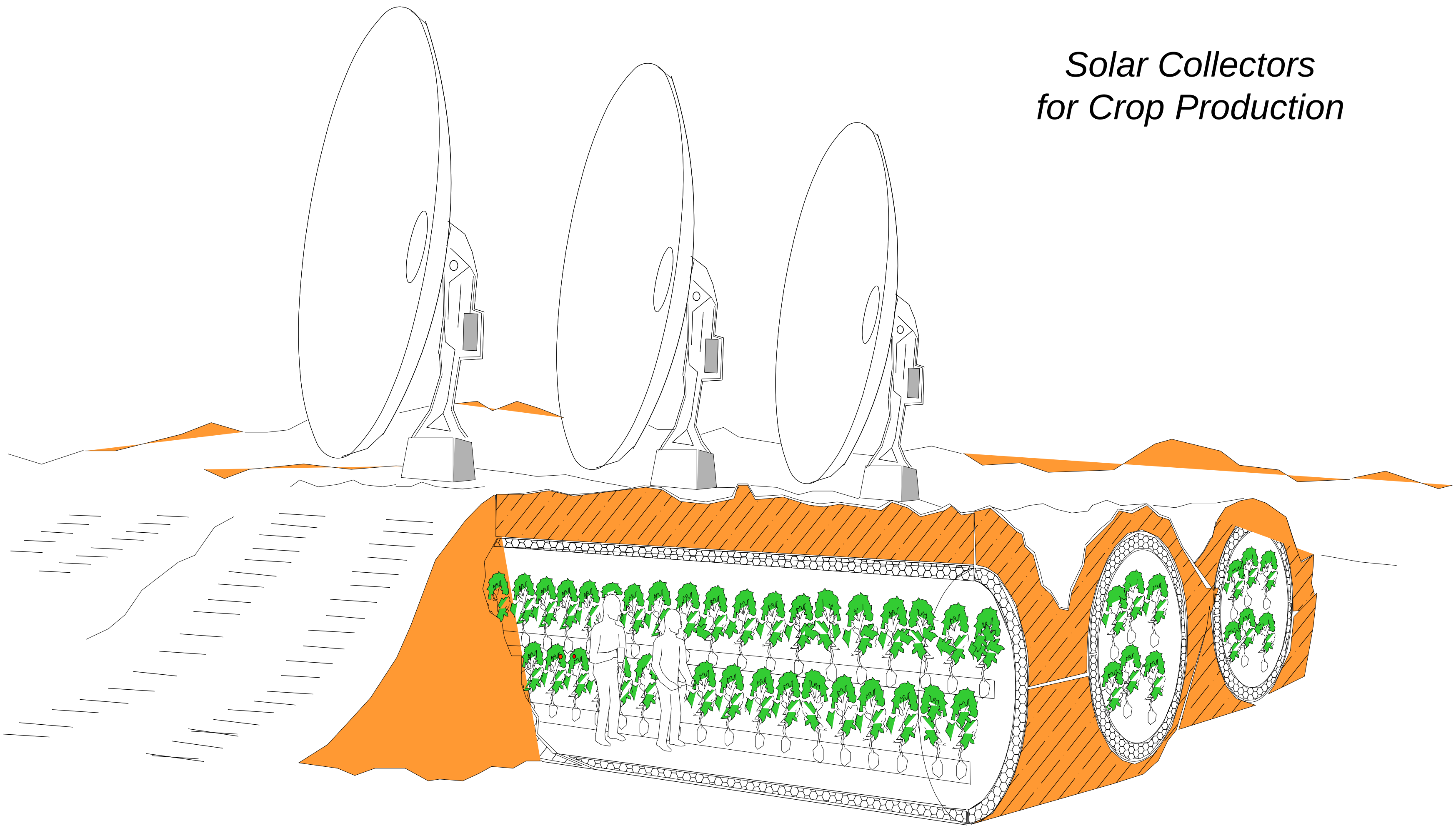
Nakamura et al. 2010. Habitation

The Importance of Light for Crop Yield



Wheeler et al. 1996. Adv. Space Res.

Solar Collectors for Crop Production



Buried Plant Growth Chambers

Sadler and Giacomelli, 2002
Life Sup. Biosphere Sci.

Photosynthetic Radiation at Mars Surface over 2 Martian Years *(J. Clawson, 2006)*

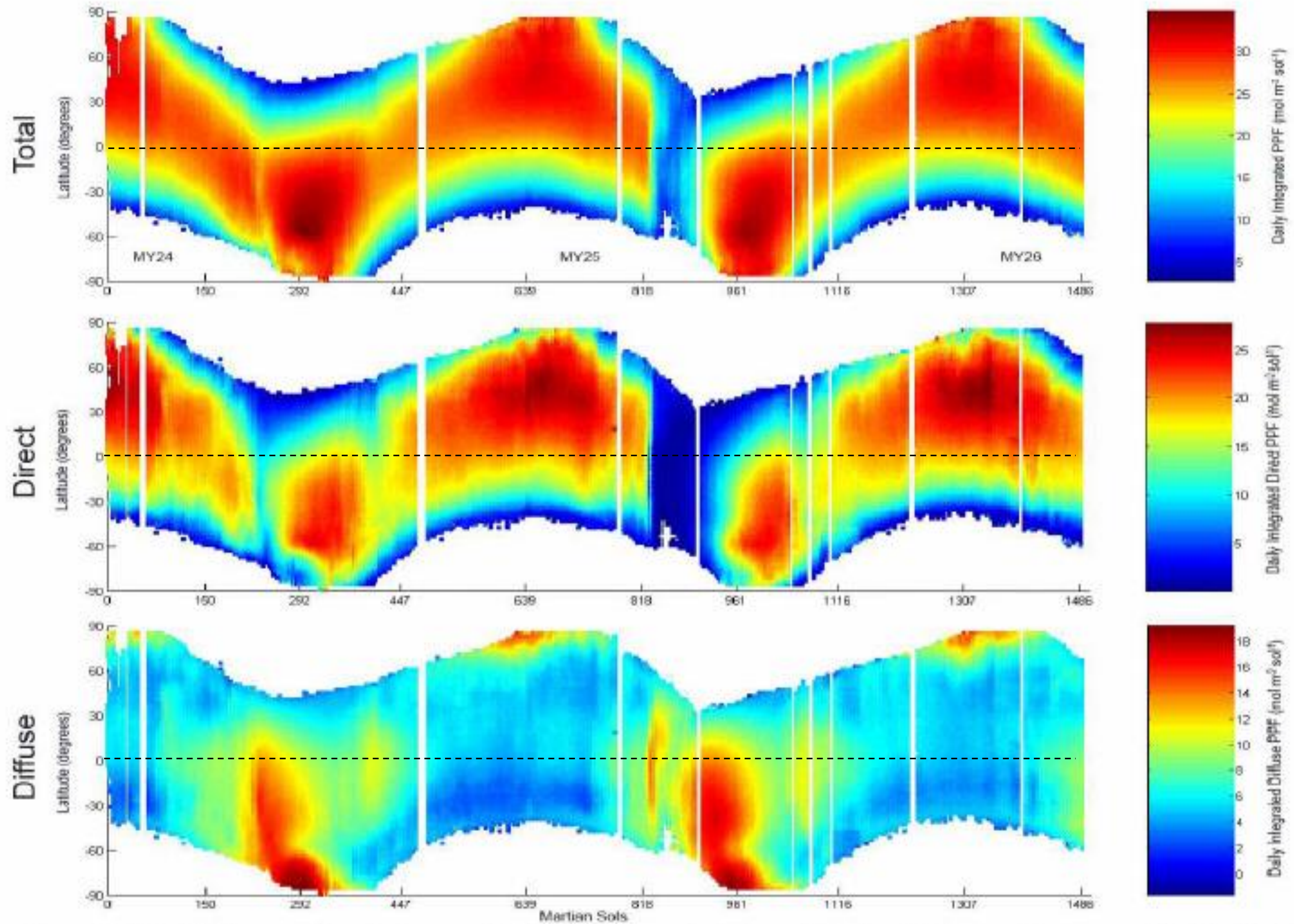
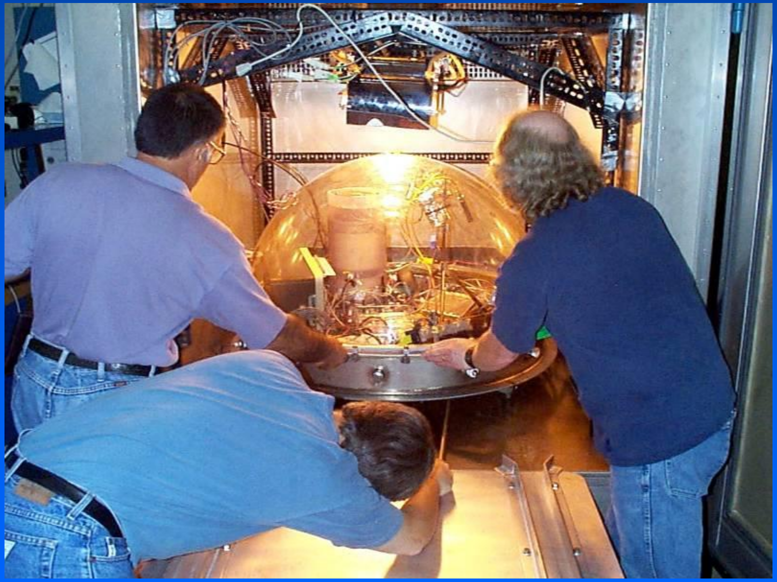


Figure 11 The daily integrated total, direct, and diffuse PPF versus latitude and Martian Sol for two Mars years. The labeled sols correspond to the start of each season on Mars. For example, sol 150 corresponds to the Northern Autumnal equinox.

University of Arizona Lunar / Mars Greenhouse

Deployable Mars Greenhouse - Low Pressure Systems



Hypobaric Testing with Plants

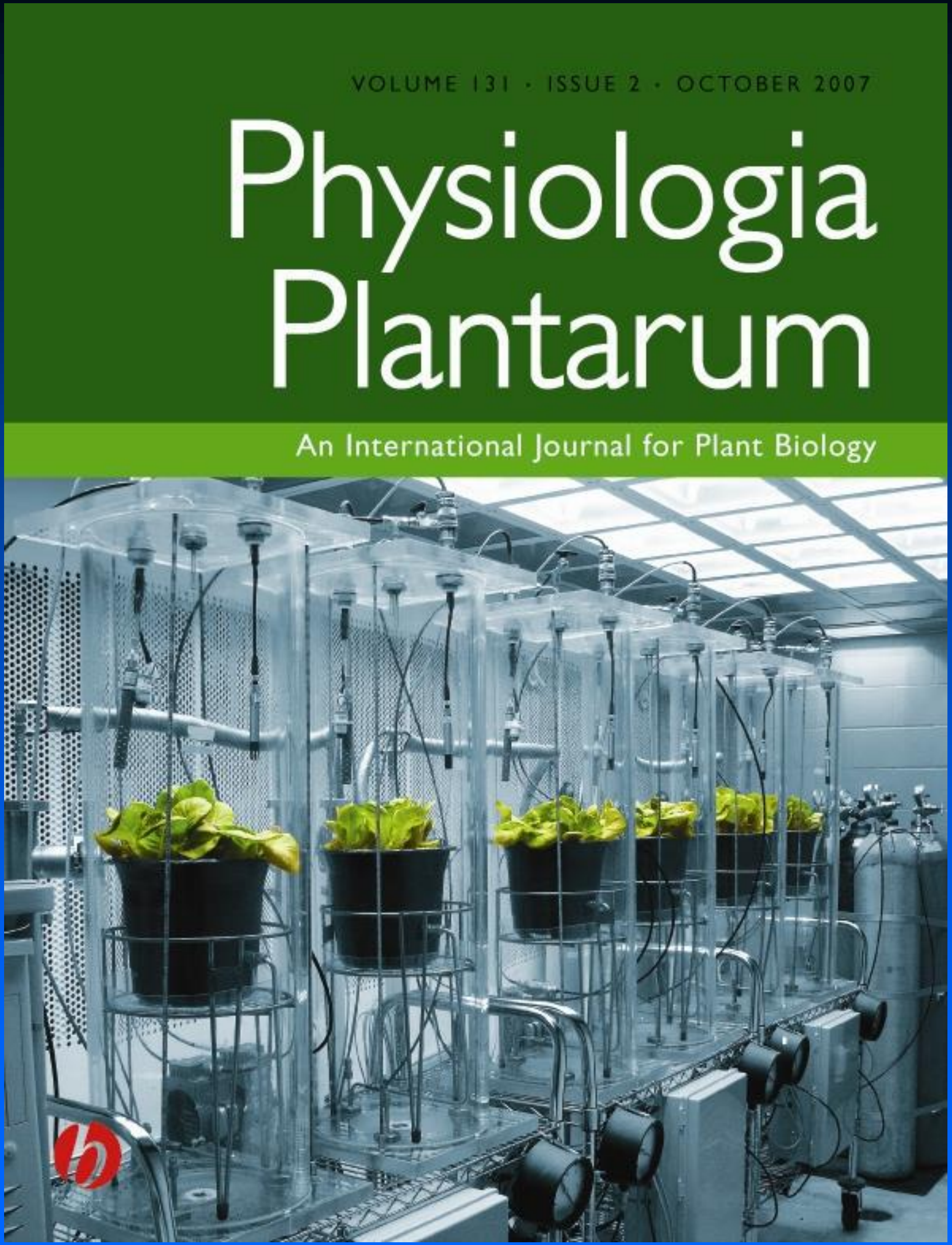
Testing at:

NASA KSC

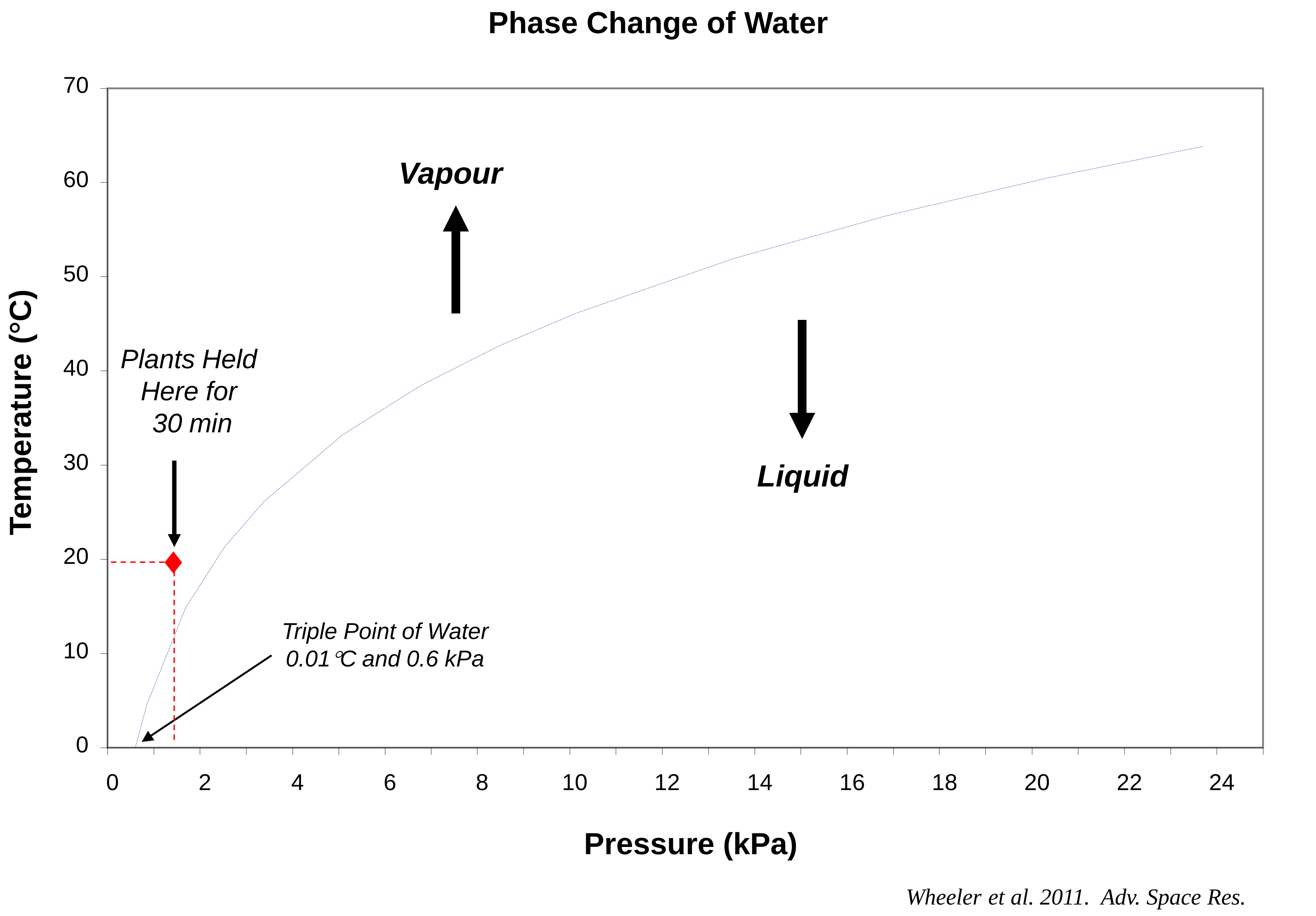
Univ. of Guelph

Texas A&M ⇒

Univ. of Florida

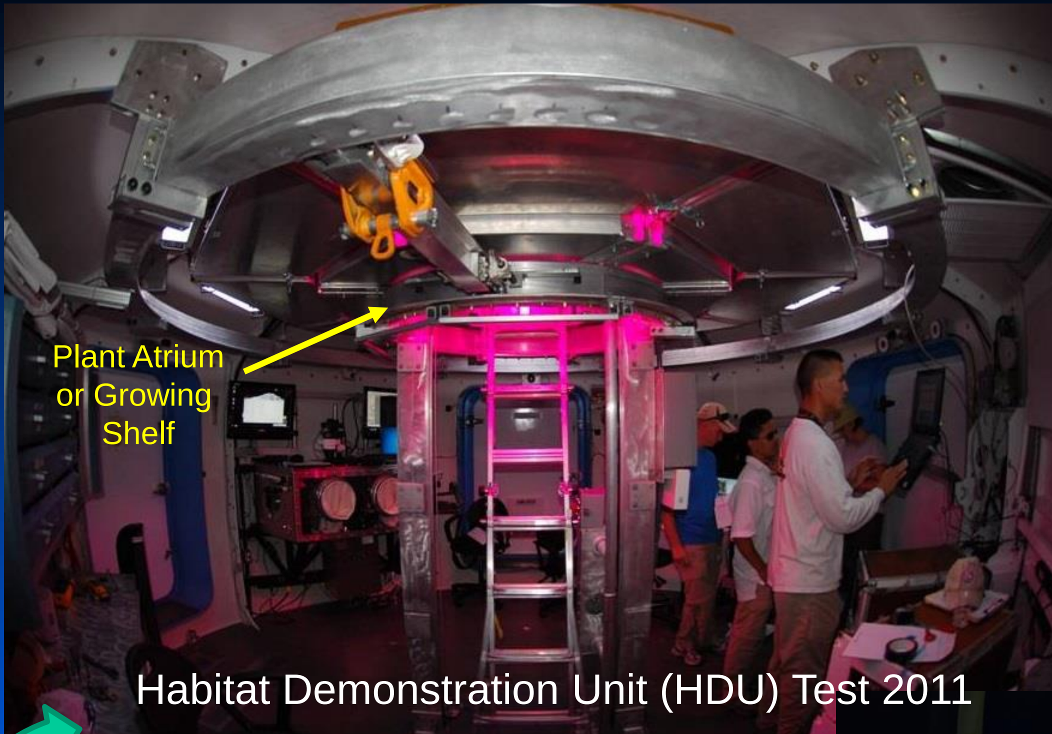


Lettuce, radish, and wheat plants exposed to rapid pressure drop (27 days old)



Phase Change of Water
Vapour
Liquid
Plants Held Here for 30 min
Triple Point of Water 0.01 ℃ and 0.6 kPa
Temperature (°C)
Pressure (kPa)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20
22
24
Wheeler et al. 2011. Adv. Space Res.

Human Habitats and Crops for Supplemental Food

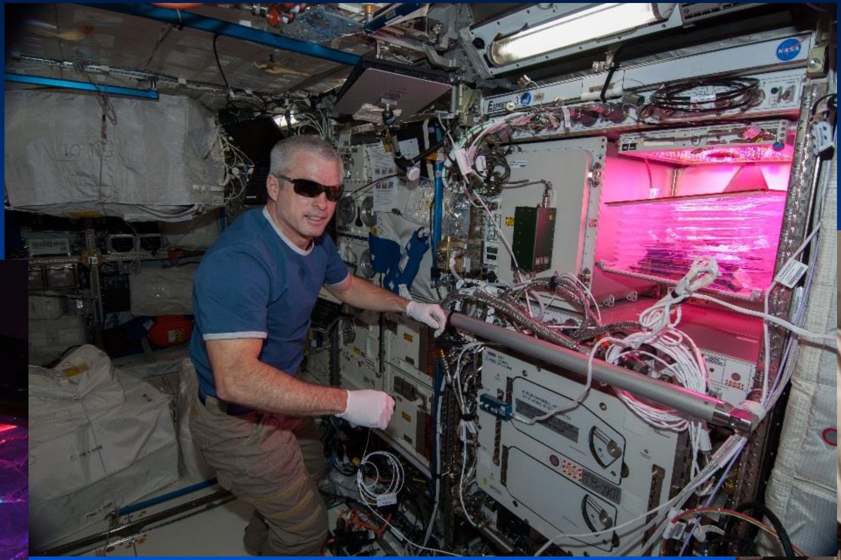


Habitat Demonstration Unit (HDU) Test 2011


HDU Test 2012

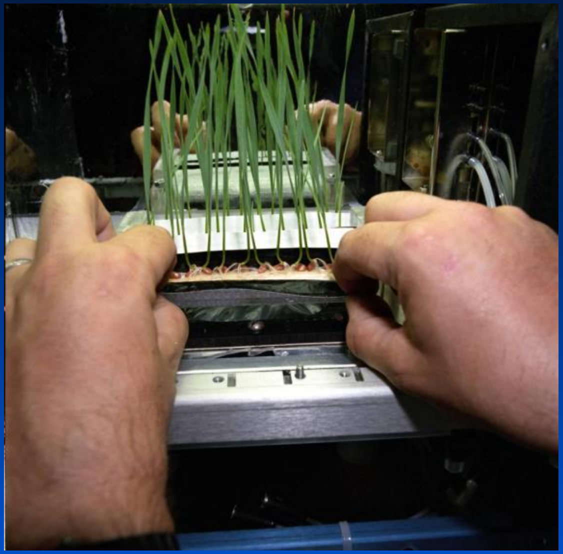
NASA's HDU at Desert Test Site

Current Plant Testing on the International Space Station—VEGGIE Plant Chamber



Passive Capillary Watering

Watering Systems for Weightlessness -- Special Challenges



Porous Ceramic Tubes to Contain the Water

Dreschel and Sager. 1989. HortScience
Morrow and Crabb. 2000. Adv. Space Res.

Porous Ceramic to Sub-irrigate Growing Media

Some other Benefits of Plants in Space

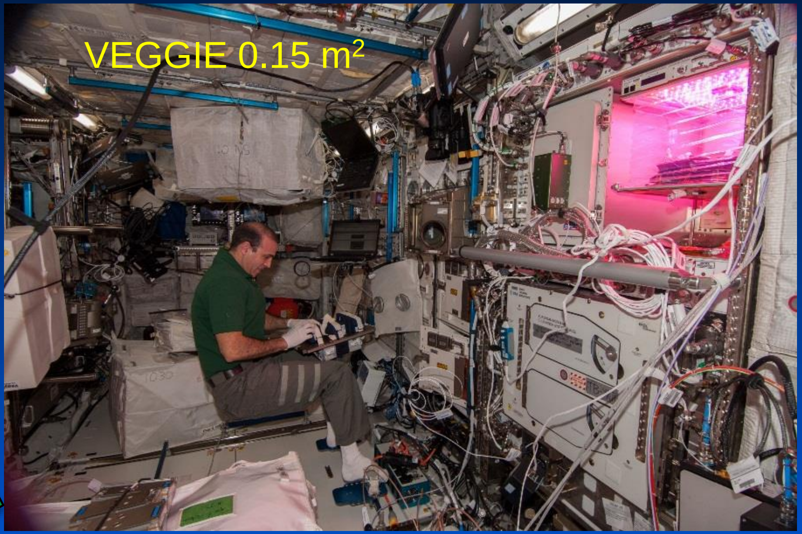
- Fresh Foods
  - *Colors*
  - *Texture*
  - *Flavor*
  - *Nutrients*
- Bright Light
- Aromas
- Gardening Activity

Kliss et al. 2000. Adv. Space Res.

Plant Chamber at US South Pole Station

Plants and Human Well-Being—Biophilia Concept? (E.O. Wilson)

Sequential Development for Space Agriculture



NASA "Salad" Crops for Near Term Missions

- "Pick-and-Eat" Fresh Food for ISS
  - Lettuce
  - Chinese Cabbage
  - Mizuna
  - Dwarf Tomato
  - Dwarf Pepper

Massa et al. 2013. Grav. and Space Res.

Technologies from “Space” Agriculture

*LEDs for growing plants--
patented through NASA
funded center at Univ.
of Wisconsin, ca. 1990*

*Potatoes in NFT at NASA KSC 1992, ↑
and at commercial “seed potato”
facility (Sklarczyk Farms, MI) 2016 ↓*

Agriculture in Space

As we explore sustainable living for space, we will learn more about sustainable living on Earth

Some Lessons Learned from NASA CEA Research

- 20-25 m^2 of crops could provide all the O_2 for one person, and 40-50 m^2 all of the food (dietary calories)
- Better adapted crops are needed—short growth, high harvest index, improved nutrition—Use genetic engineering?
- Lighting is key to sustaining high yields
- CEA systems require large quantities of water (e.g., 50 L m^{-2}) and this water must be recycled.
- Up to 90 kg of fertilizer would needed per person per year, emphasizing the need for recycling nutrients.
- Plants can provide psychological benefits to humans—this needs further study.
- The use of agriculture for space life support will likely evolve sequential, as mission infrastructures expand.