Sustainable Living for Space and Earth:

Use of Plants and Bioregenerative Technologies

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SpaceTech 1.0

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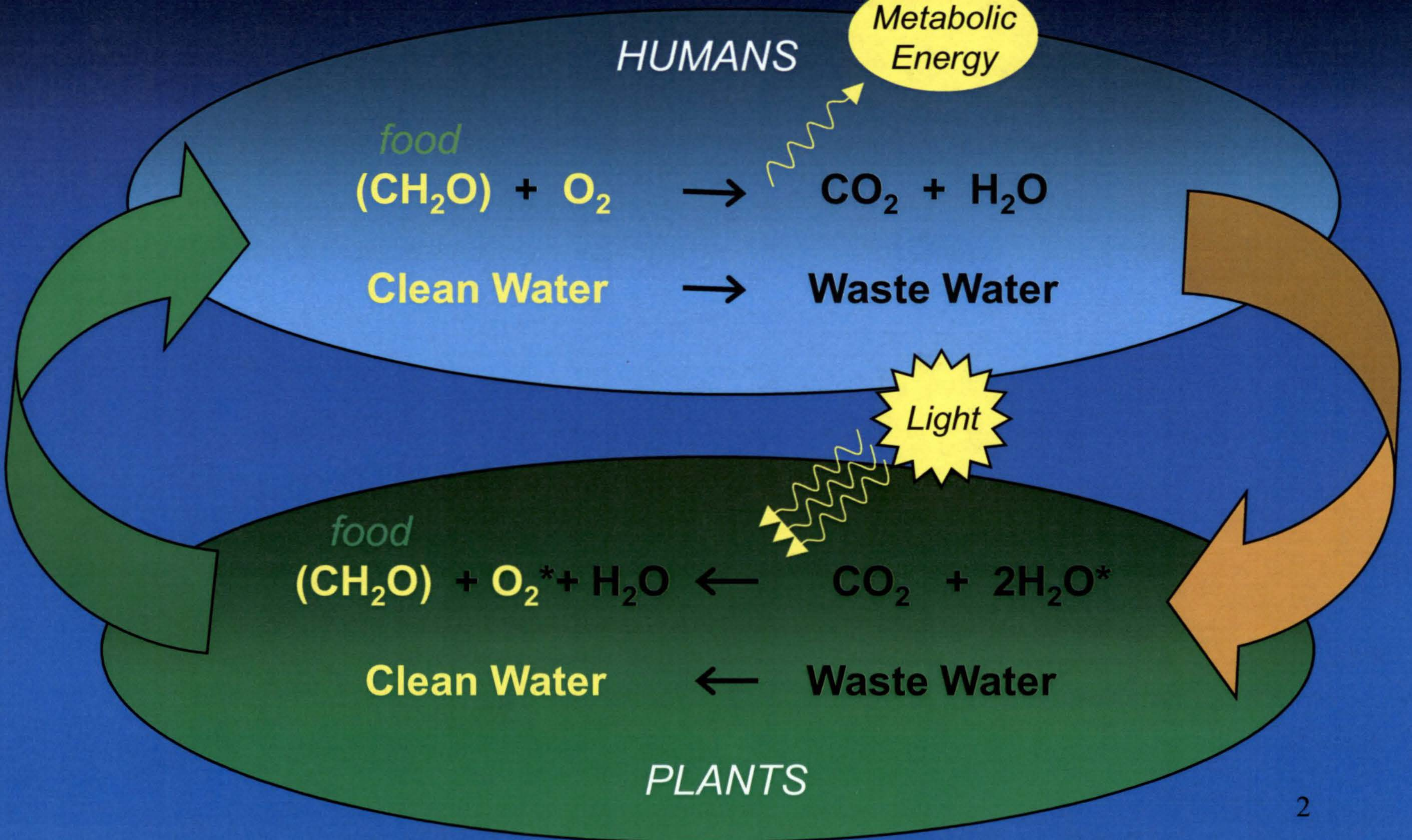
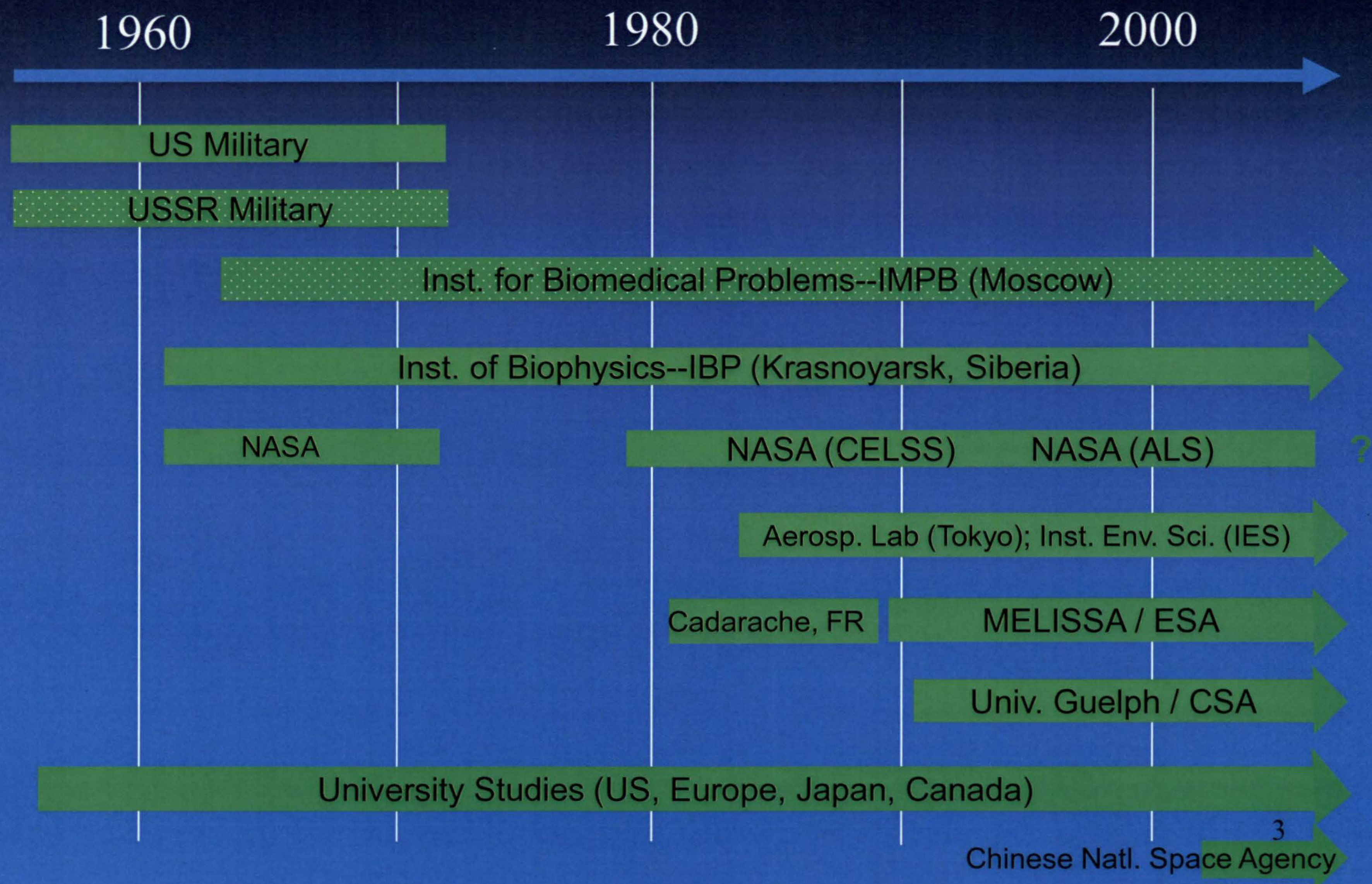
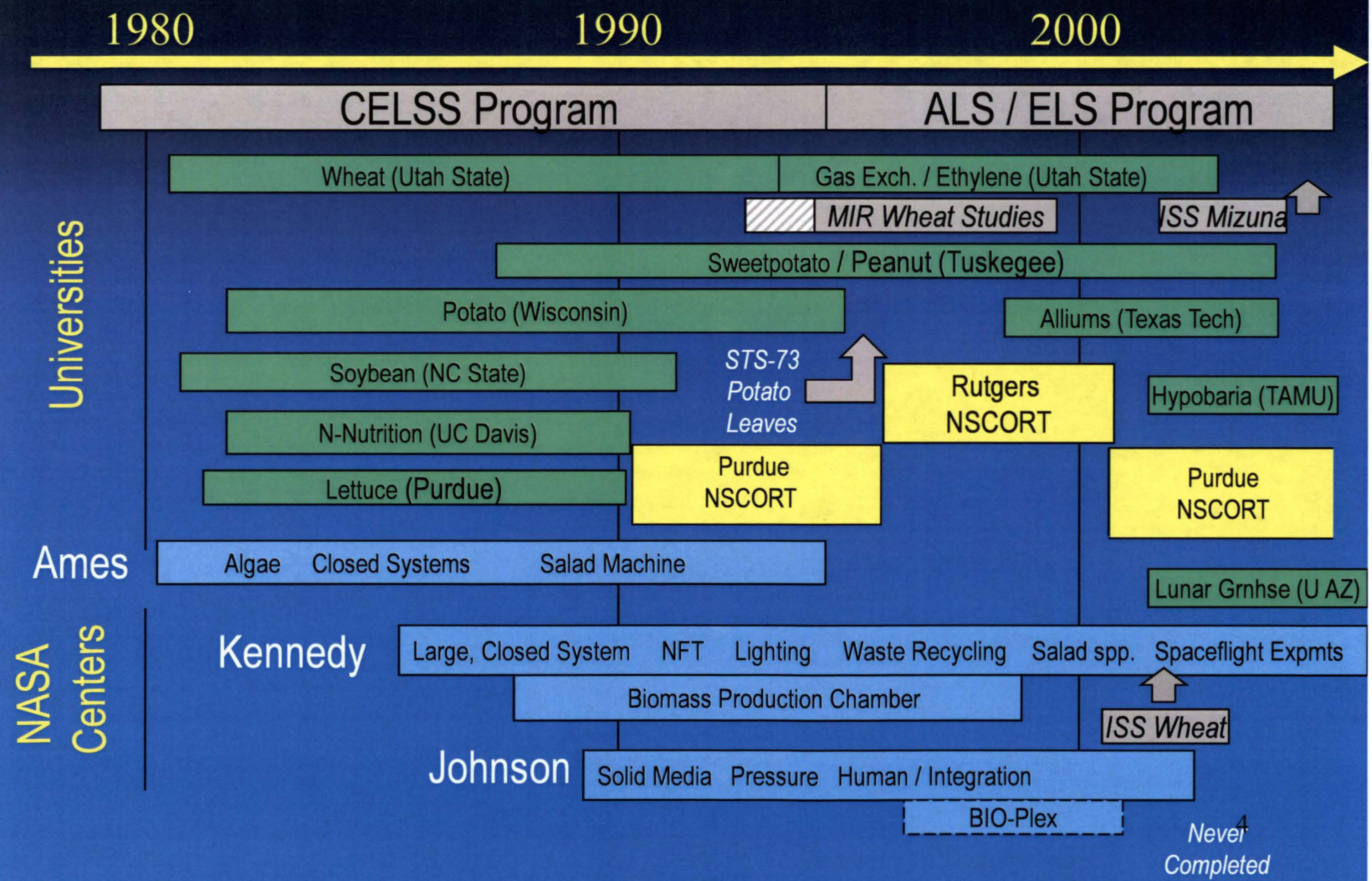
Plants for "Bioregenerative" Life Support



Bioregenerative Life Support Testing around the World



NASA's Bioregenerative Life Support Testing



Crop Considerations for Space

- High yielding and nutritious (CHO, protein, fat)
- High harvest index (edible / total biomass)
- Horticultural considerations
  - planting, harvesting, pollination, propagation
- Environmental considerations
  - photoperiod, temperature, mineral nutrition
- Processing requirements
- Dwarf or low growing types

Many of these same considerations apply for Earth

Recirculating Hydroponics with Crops

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

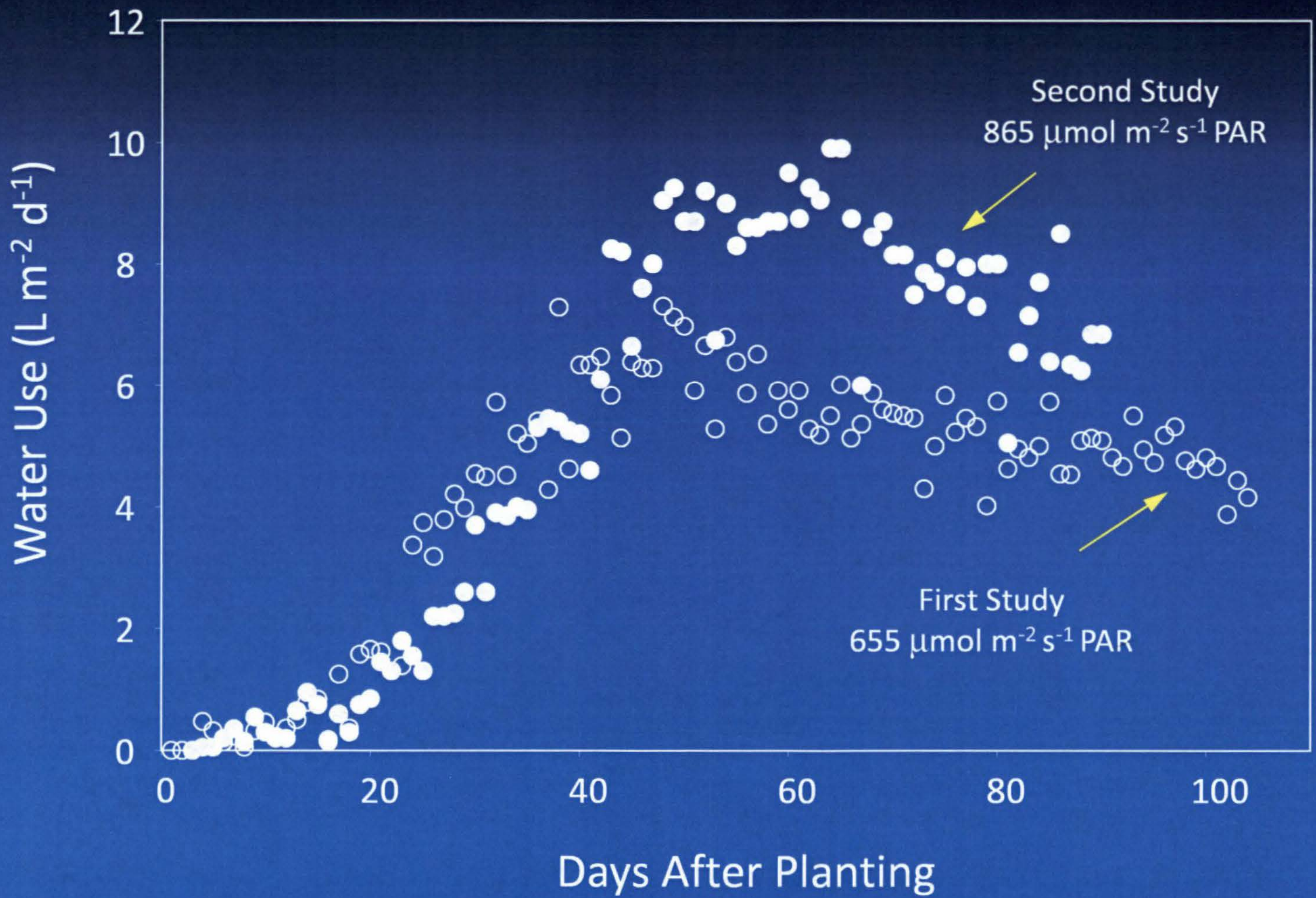
Wheeler et al., 1999. Acta Hort.

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

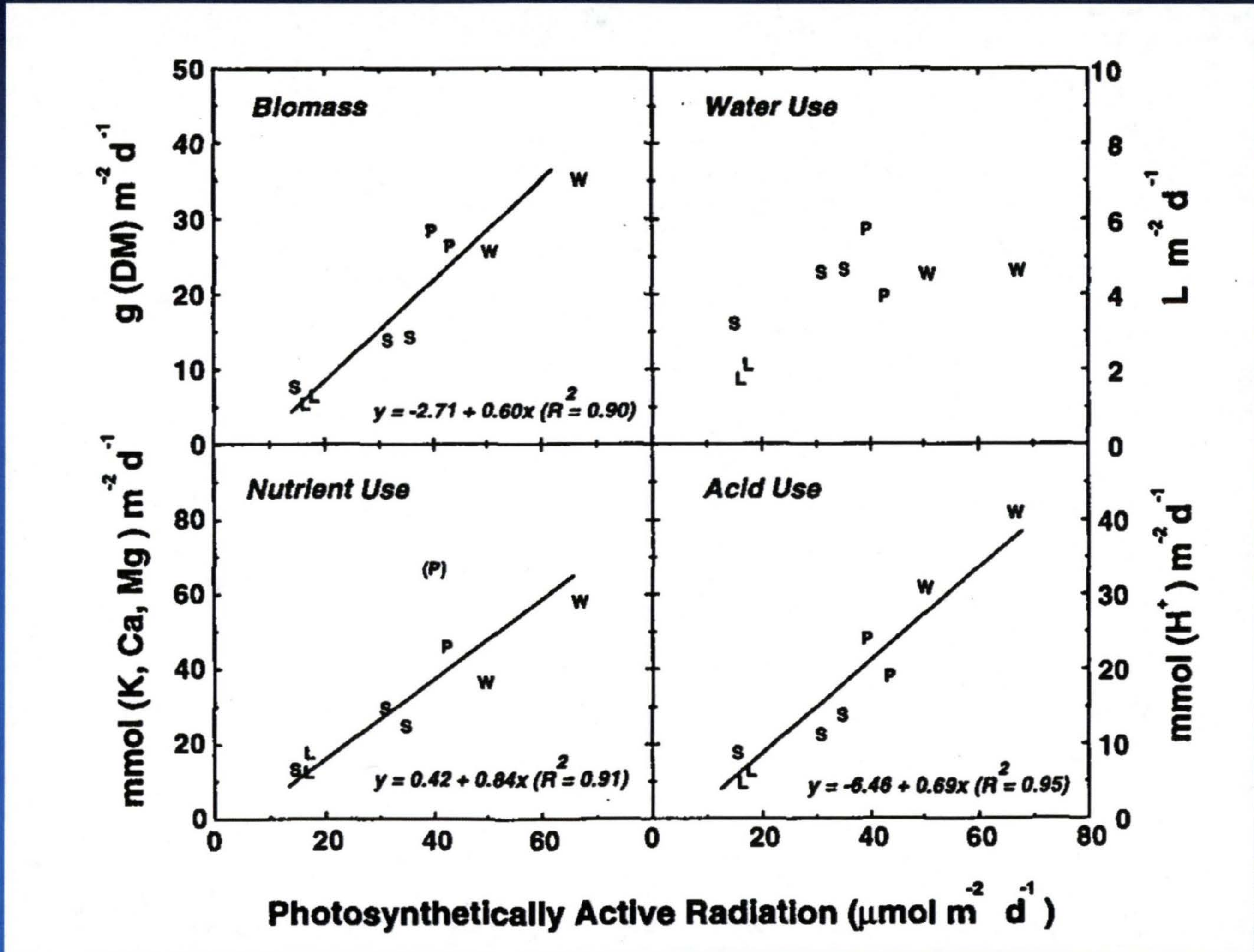
Evapotranspiration from Plant Stands (potato)

→*Water Recycling for Space and Earth are Key*



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

Water, Nutrient, and pH Control for Recirculating Hydroponic Systems



Wheeler et al. 1999. Acta Hort.

The Importance of Lighting
--Electric Lamp Options

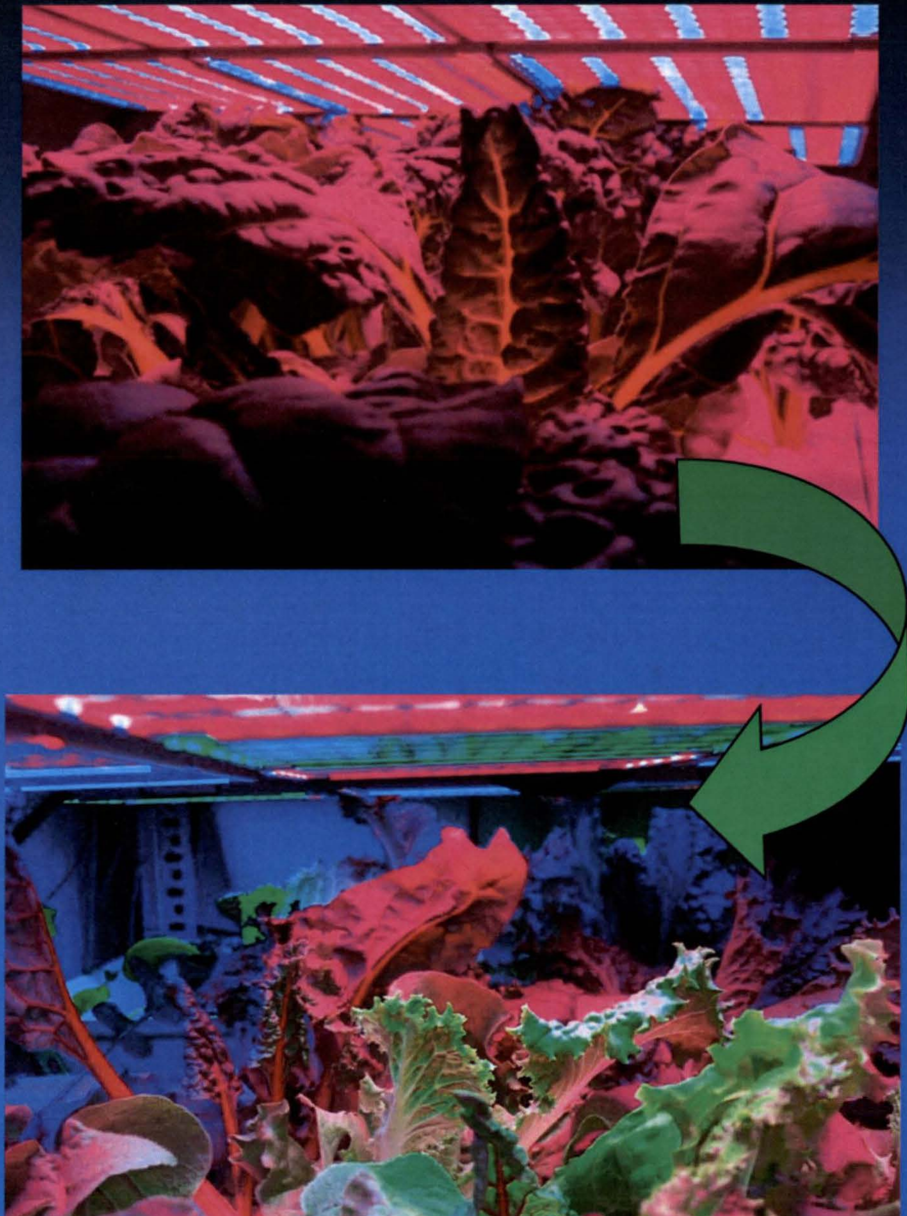
	Lamp Type	*Conversion* Efficiency*	*Lamp Life* (hrs)*	*Spectrum*
•	Incandescent/Tungsten**	5-10%	2000	Intermd.
•	Xenon	5-10%	2000	Broad
•	Fluorescent***	20%	5,000-20,000	Broad
•	Metal Halide	25%	20,000	Broad
•	High Pressure Sodium	30%	25,000	Intermd.
•	Low Pressure Sodium	35%	25,000	Narrow
•	Microwave 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

Some NASA Related References:

Bula et al. 1991. HortSci 26:203-205.

Barta et al. 1992. Adv. Space Res. 12(5):141-149.

Tennessen et al. 1994. Photosyn. Res. 39:85-92.

Goins et al. 1997. J. Exp. Botany 48:1407-1413.

Kim et al. 2004. Ann. Bot. 94:691-697.

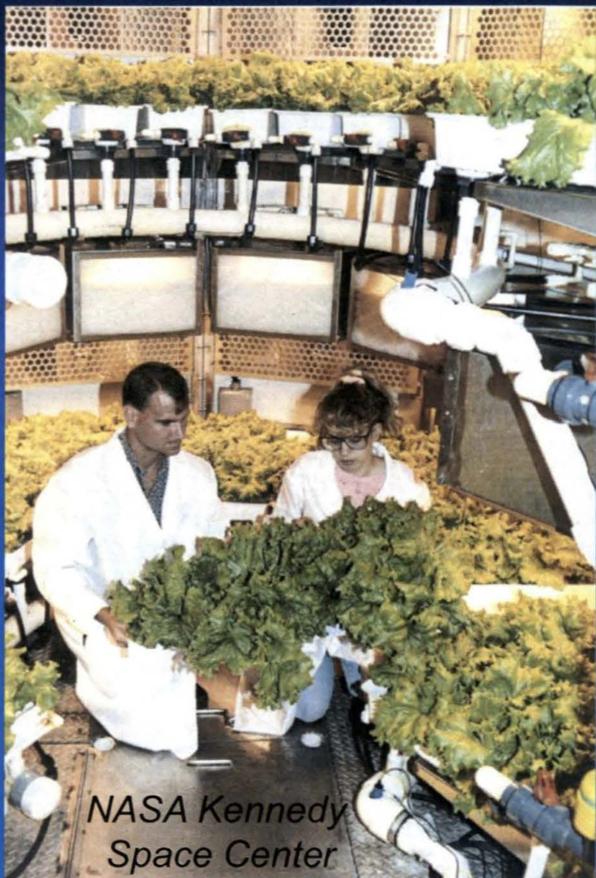
Solar Collector / Fiber Optics For Plant Lighting

2 m^2 of collectors on solar tracking drive (SLSL Bldg, 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

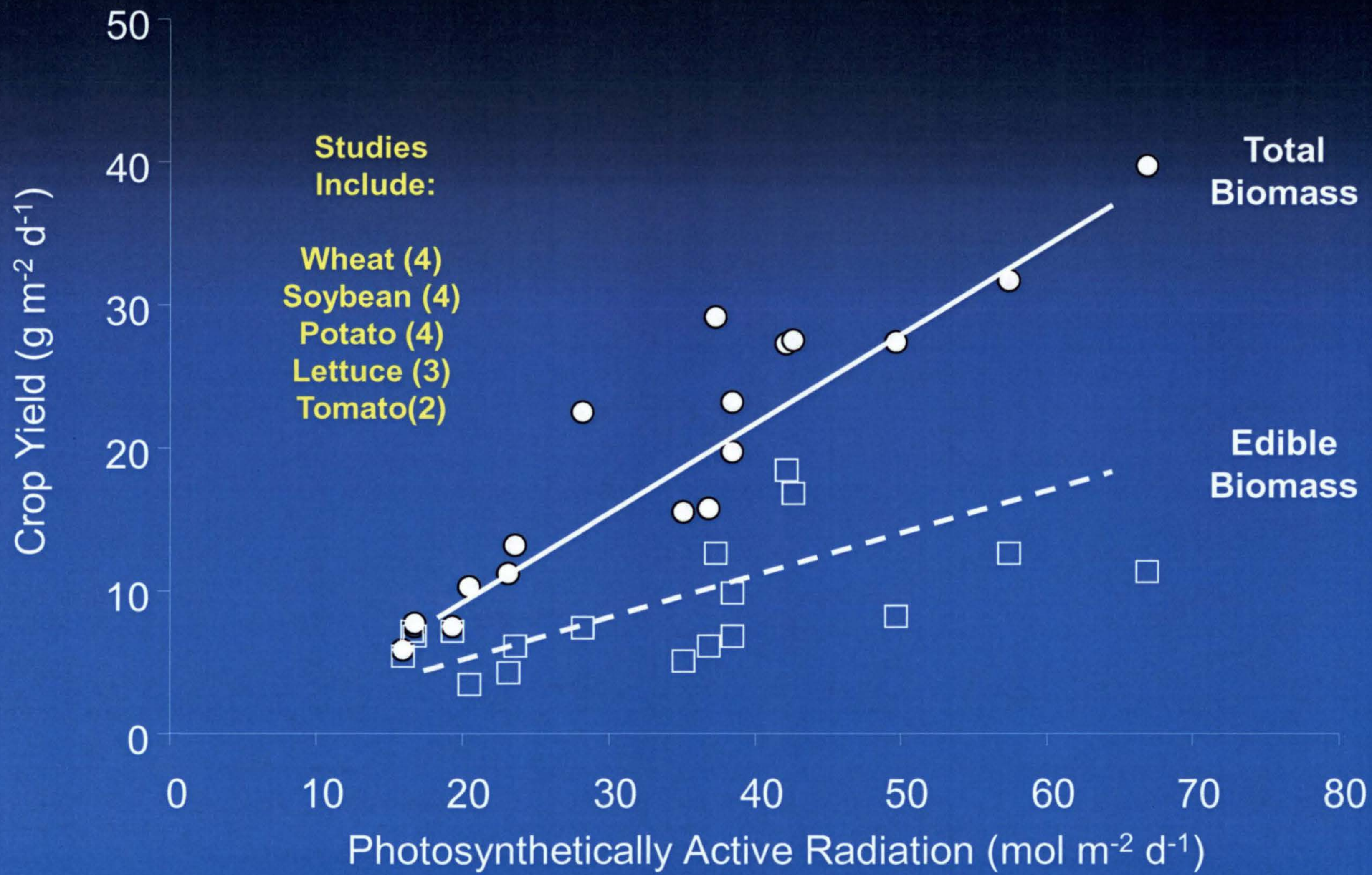
High Yields from High Light and CO_2 Enrichment



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

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.

Effect of Light on Crop Yield



Wheeler et al. 1996. Adv. Space Res .

Potential Energy Conversion to Biomass

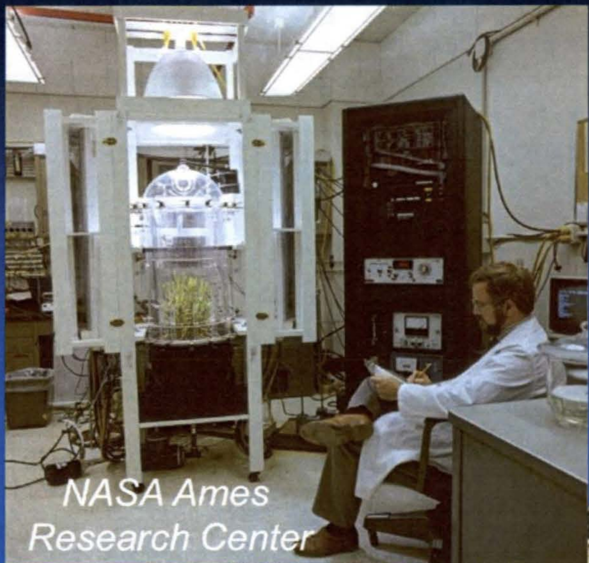
From Loomis and Williams. 1963. Crop Science 3:67-72

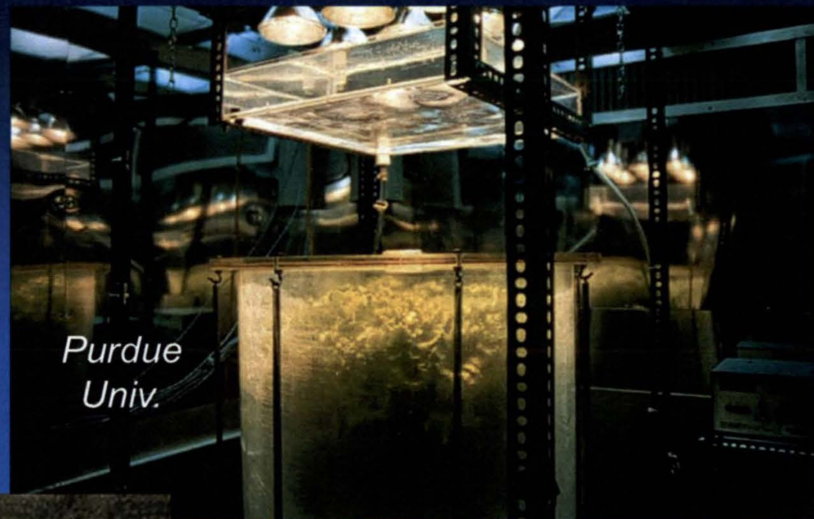
Assuming a maximum 12% conversion efficiency from PAR to biomass[1]

1.6 g dry mass / mol PAR

[1] Radmer and Kok. 1977. BioScence. Actual instantaneous conversion efficiencies of~10% reported from some controlled environment studies ; e.g., Wheeler et al. 1993. Crop Sci; Gerbaud et al. 1998. Physiol. Plant.

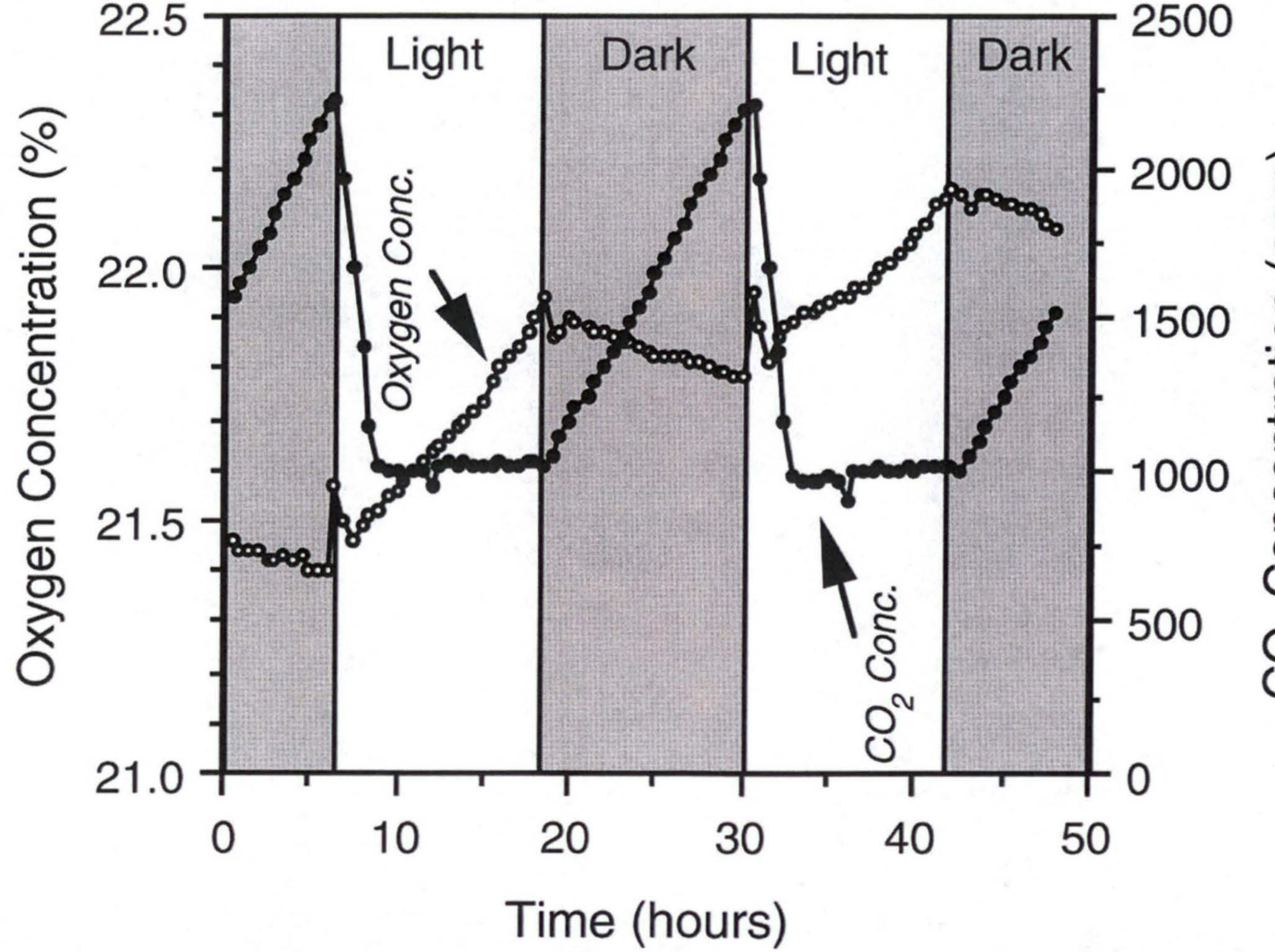
Closed Systems Issues





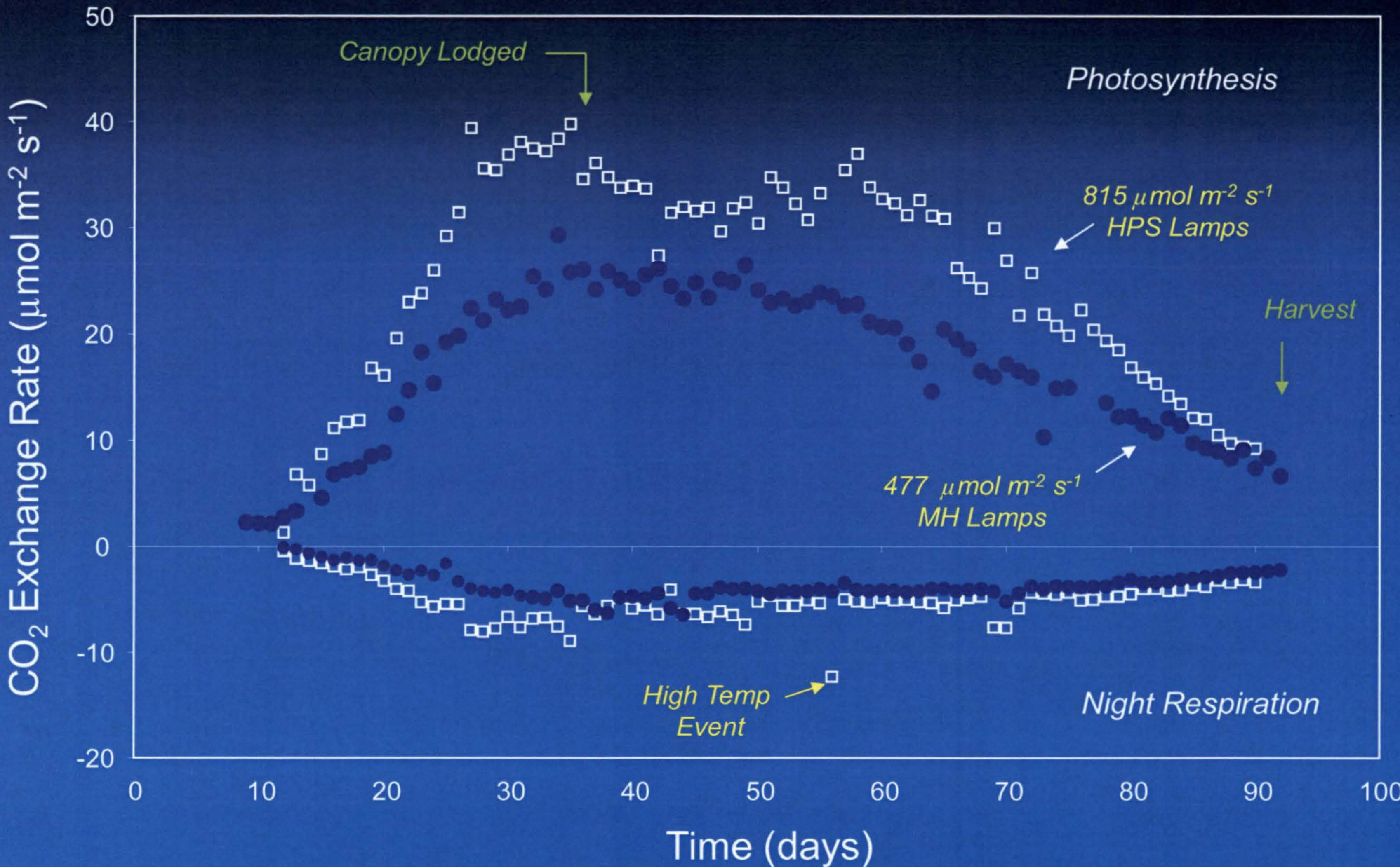
Canopy CO_2 Uptake / O_2 Production

(20 m^2 Soybean Stand)



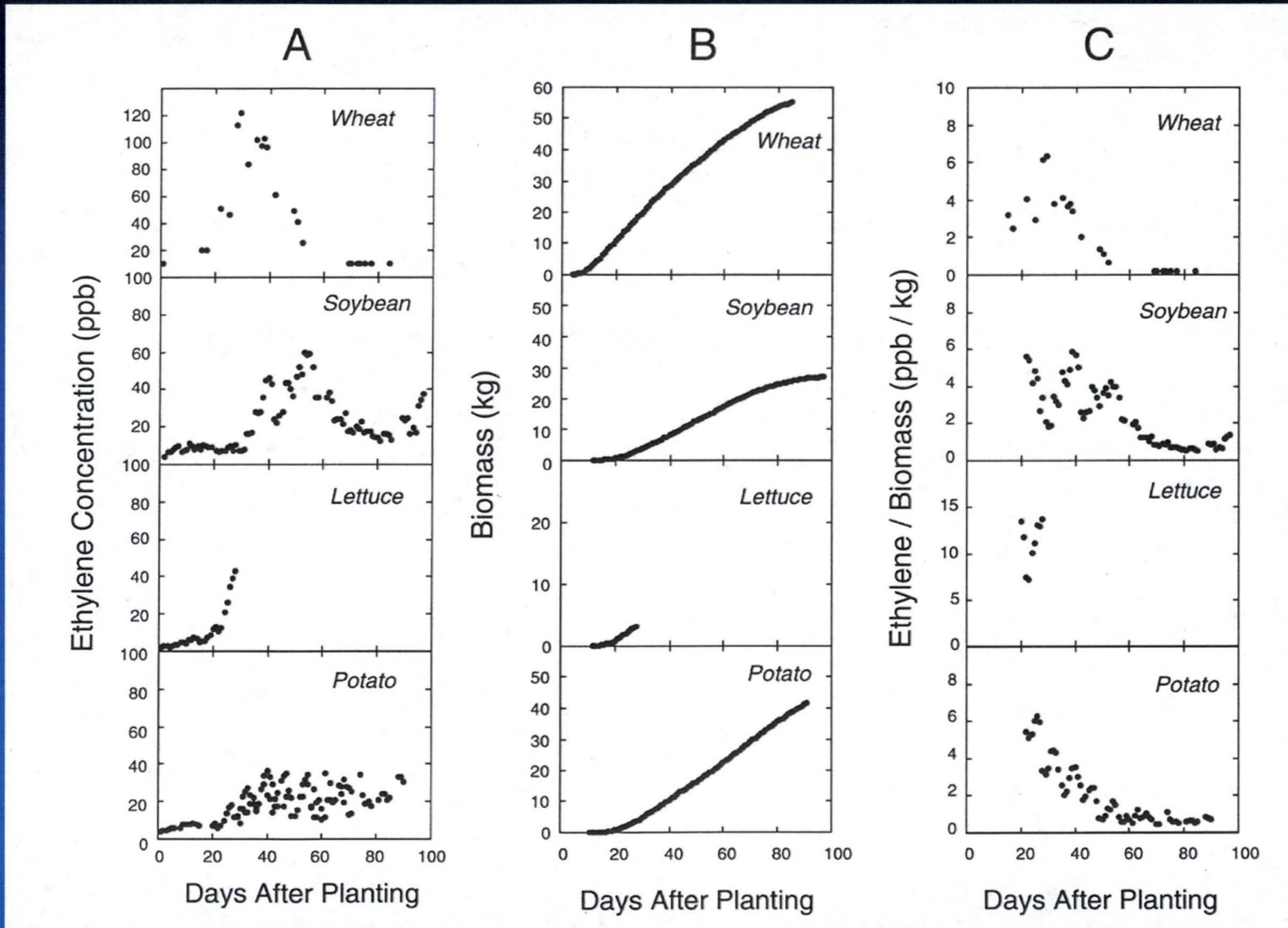
Wheeler. 1996. *In:* H. Suge (*ed.*) Plants in Space Biology.

CO_2 Exchange Rates of Soybean Stands



Wheeler et al., 2004. EcoEngineering.

Canopy / Stand Ethylene Production



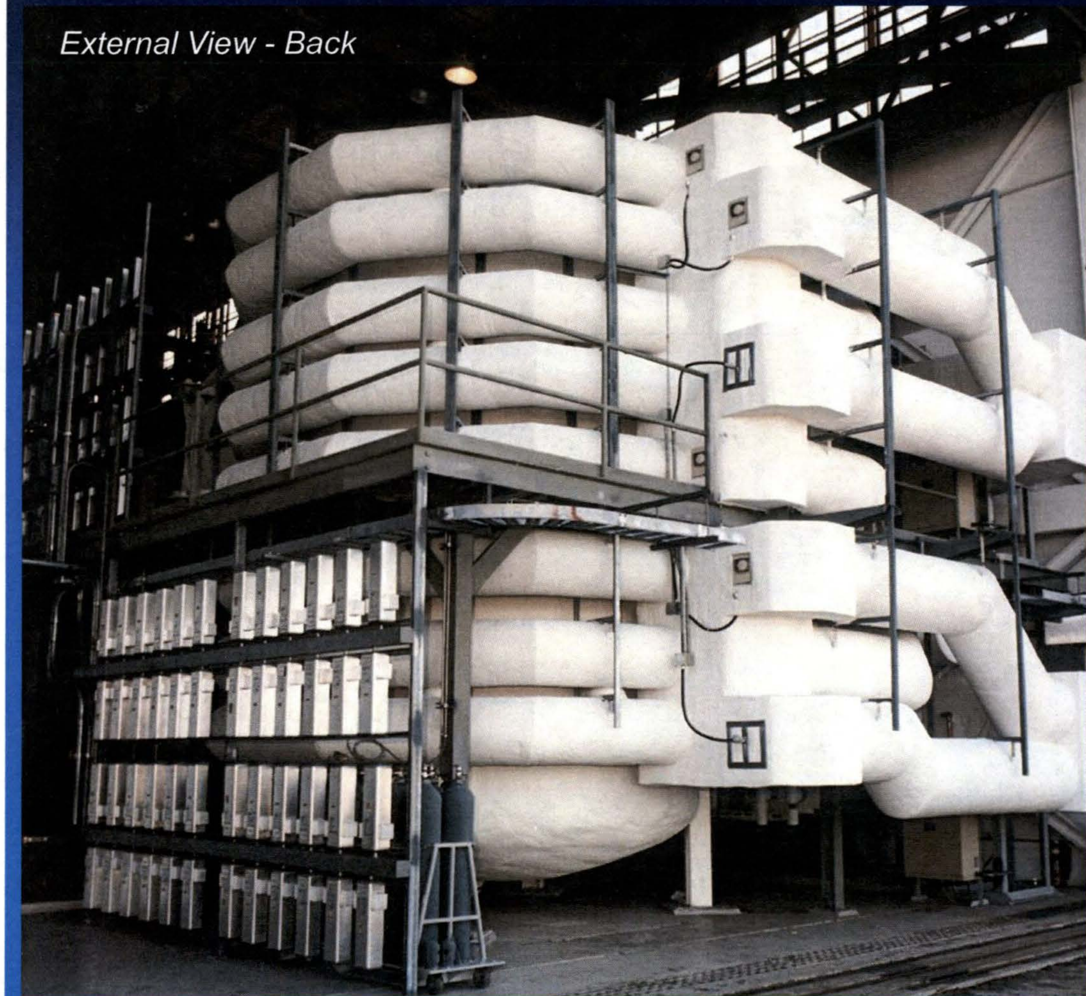
Wheeler et al. 2004. HortScience 39:1541-1545.

Ethylene in Closed Systems

Epinastic
Wheat Leaves
at ~120 ppb

Epinastic
Potato Leaves
at ~40 ppb

NASA's Biomass Production Chamber (BPC)



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

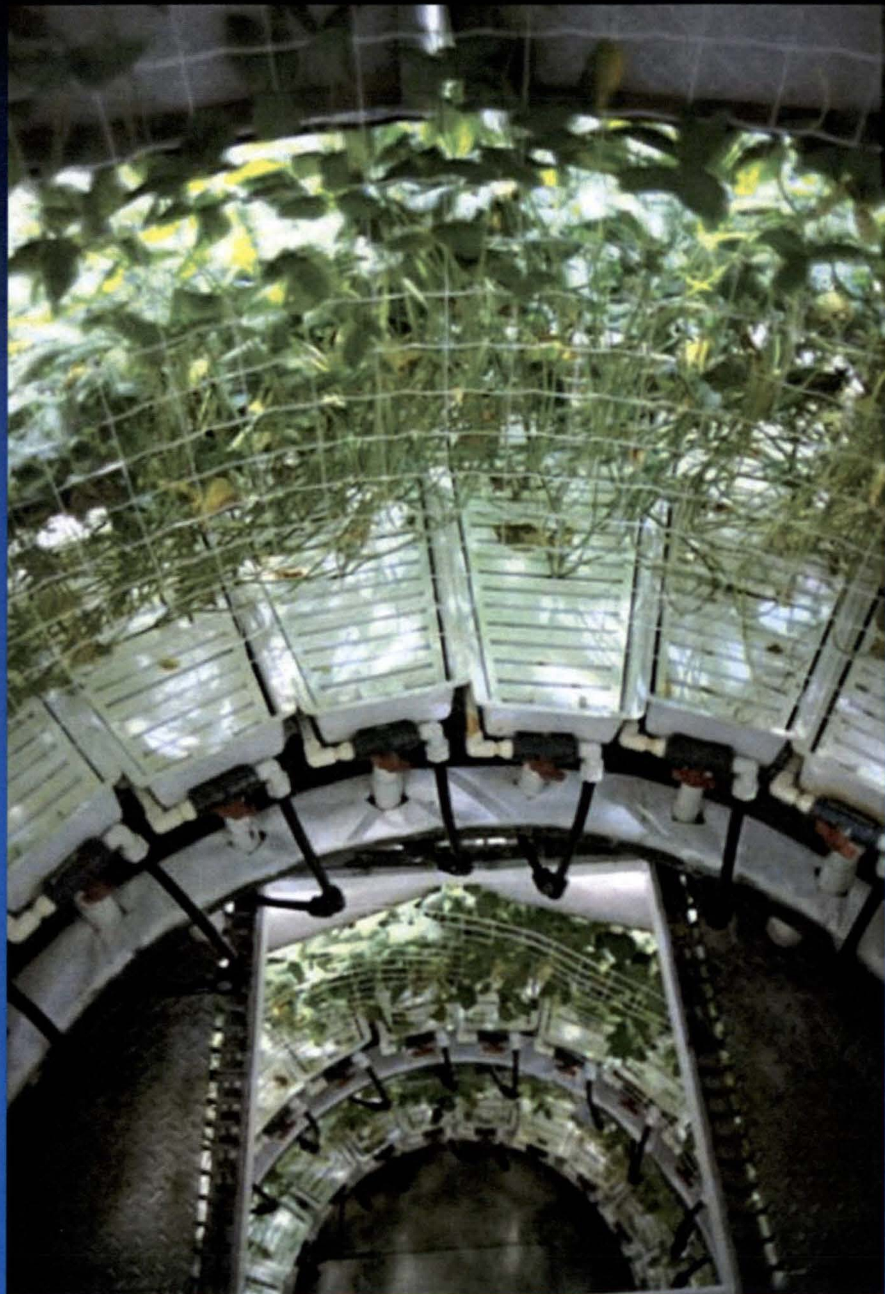
NASA's Biomass Production Chamber (BPC)

Wheat

(Triticum aestivum)

planting

harvest

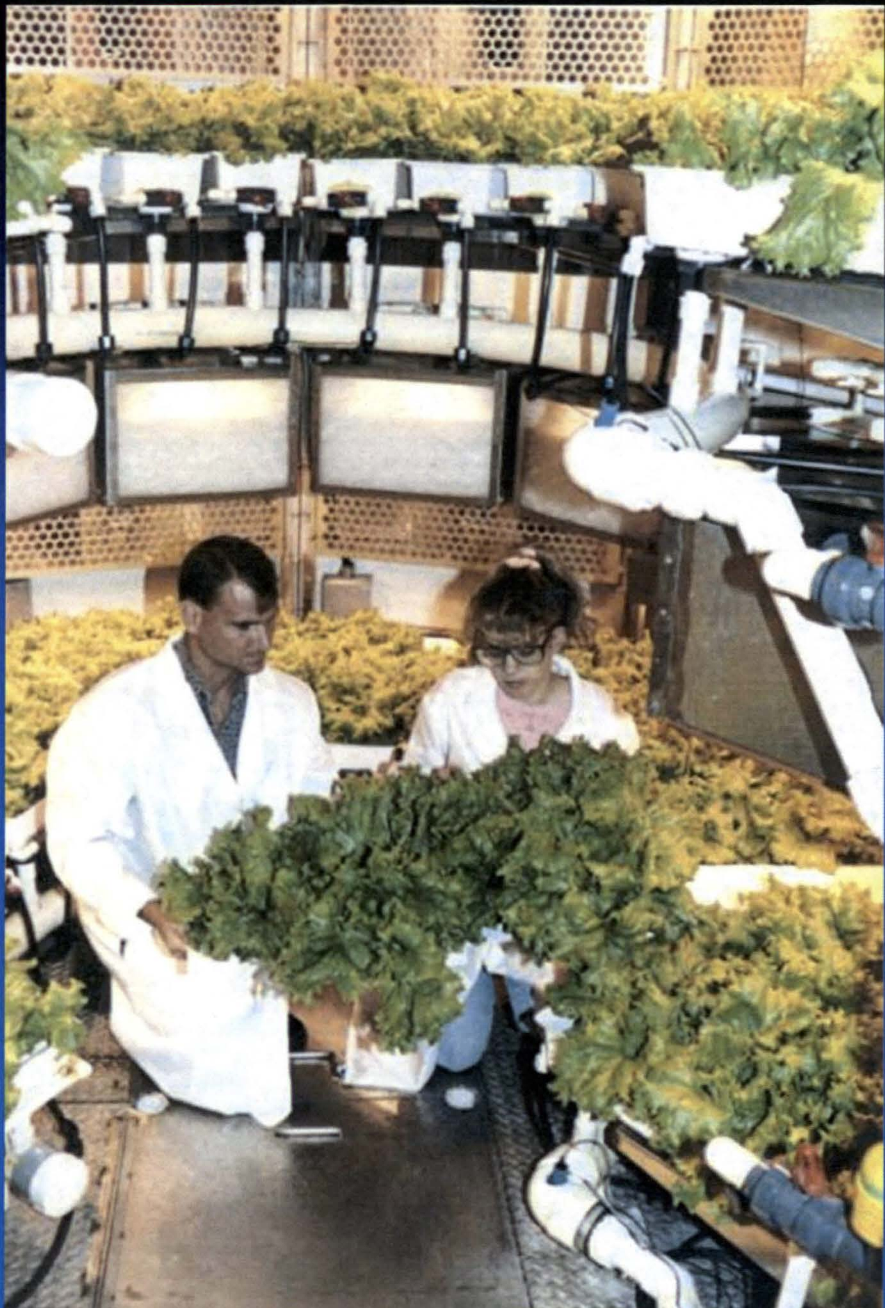


Soybean

(Glycine max)

Lettuce

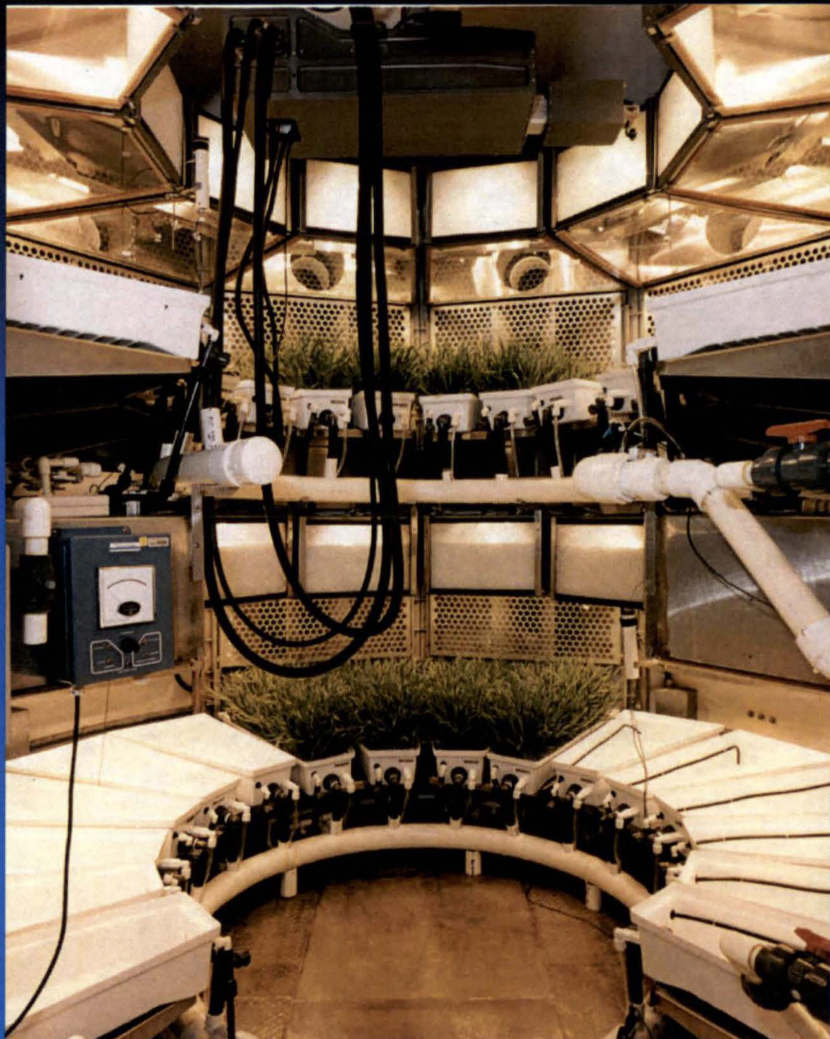
(Lactuca sativa)



Potato

(Solanum tuberosum)

Automation Technologies for CEA



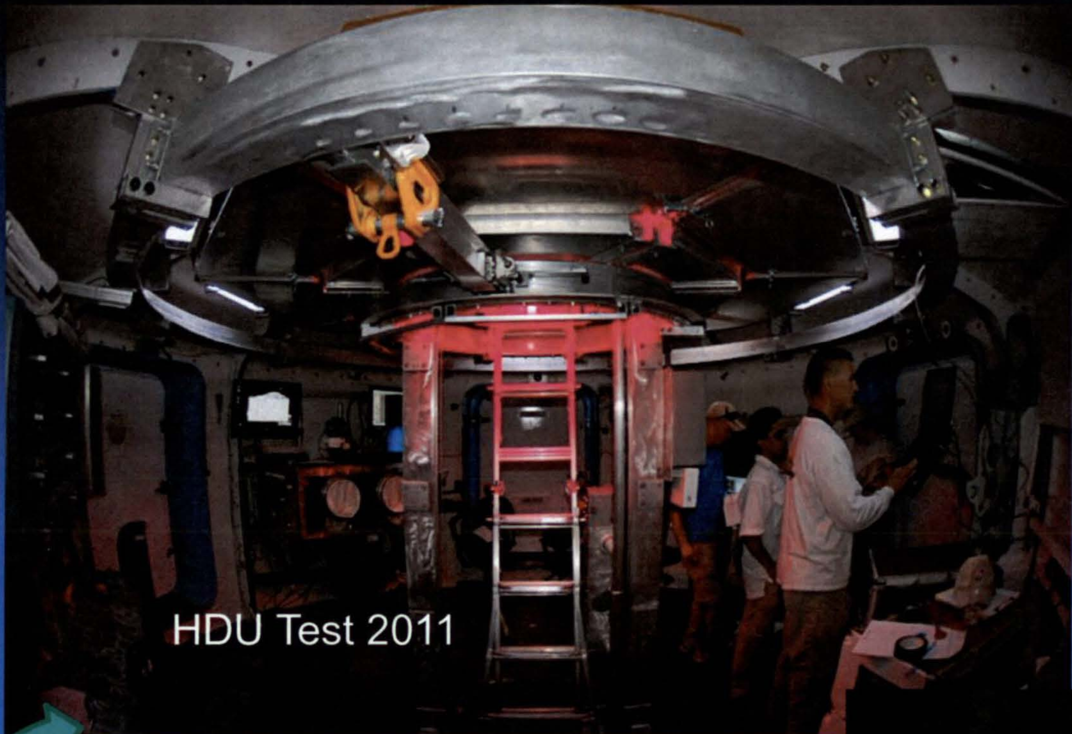
ALSARM Robot in NASA Biomass Production Chamber

Integrated Testing with Humans

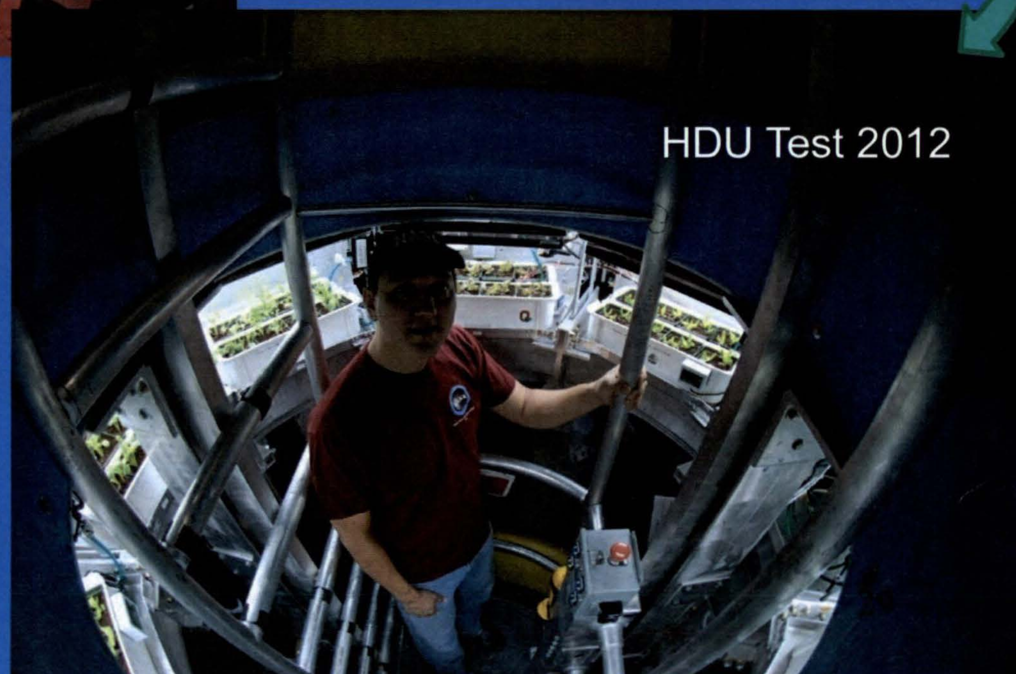
→ *One Human and 11 m² of Wheat !*

Nigel Packham, NASA Johnson Space Center

Current Testing: Crops for Supplemental Food



HDU Test 2011

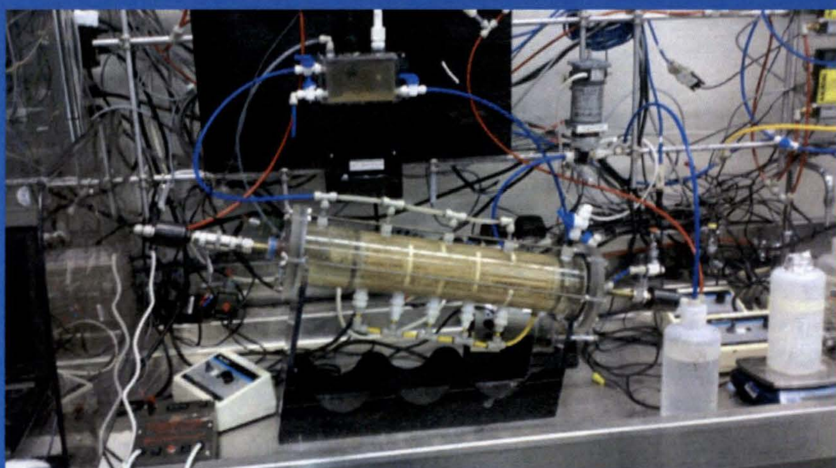


HDU Test 2012

Bioregenerative Technologies for Treating Solid and Liquid Wastes

Solid Waste Stirred Tank Reactors

Graywater and Septic Effluent Treatment



Urine Hydrolysis and Nitrification

Solid Waste / Aquaculture Systems

Mackowiak et al. 1996. Acta Hort; Garland et al. 1997. Adv. Space Res.; Morales et al. 1996. FEMS Microb. Ecol. 20:155-162.

Reducing Nutrient Discharge from Wastewater

Reducing Water Pollution
in Florida

Plant and Soil Beds to Reduce
Nutrient Discharge into
Coastal Waters and Estuaries

Loader et al., 1997, 1999. Life Sup. Biosphere Sci.

Phytofarms: A Pioneering Effort in Controlled Environment Agriculture

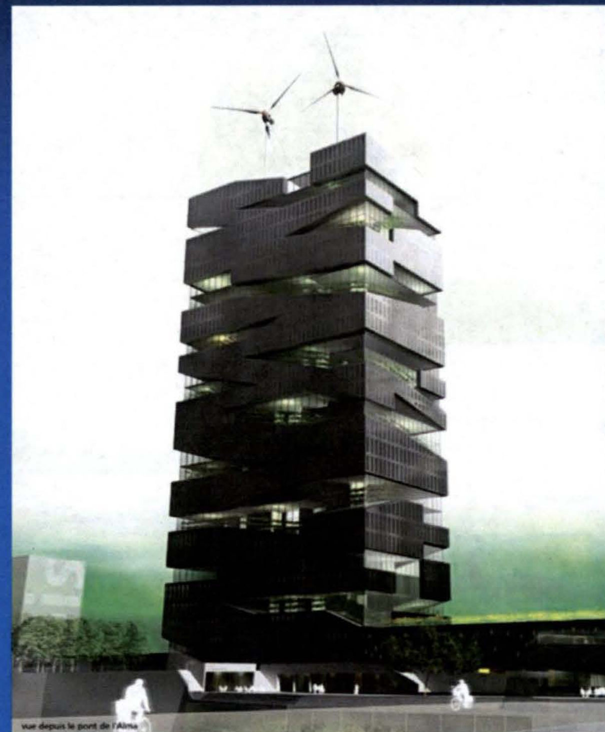
- Located in DeKalb, IL; Noel Davis, President and Founder
- Operated from late 1970s through 1980s
- Approximately 1 acre of growing area in a two-story facility
- Hydroponic production of lettuce, spinach and herbs
- Used over 1000, 1000-W water-cooled HPS lamps. Thus the facility drew ~ 1 MW of power and consequently shifted most of their demand to off-peak hours.

Phytofarms DeKalb, IL

Phytofarms, DeKalb, IL

Phytofarms
Dekalb, IL

Vertical Agriculture for Urban Settings



Graphics from Website for
D. Despomier, Columbia Univ.

Vertical Farming Happening Right Now

Texas Plant-Expressed Vaccine Consortium
Photos Courtesy of Illumitex
Austin, TX


Agriculture in Space
As we explore sustainable living for space, we will learn more about sustainable living on Earth
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KSC Advanced Life Support Team, Hangar L, KSC 1994