Development of Bioregenerative Life Support for Longer Missions:

When Can Plants Begin to Contribute to Atmospheric Management?

Raymond M. Wheeler
Surface Systems Office
NASA Kennedy Space Center
Florida, USA
raymond.m.wheeler@nasa.gov

Plant Photosynthesis

$$CO_2 + 2H_2O^{*} \xrightarrow{\textit{light}} (CH_2O) + H_2O + O_2^{*}$$

(CH_2O) → Edible (food)

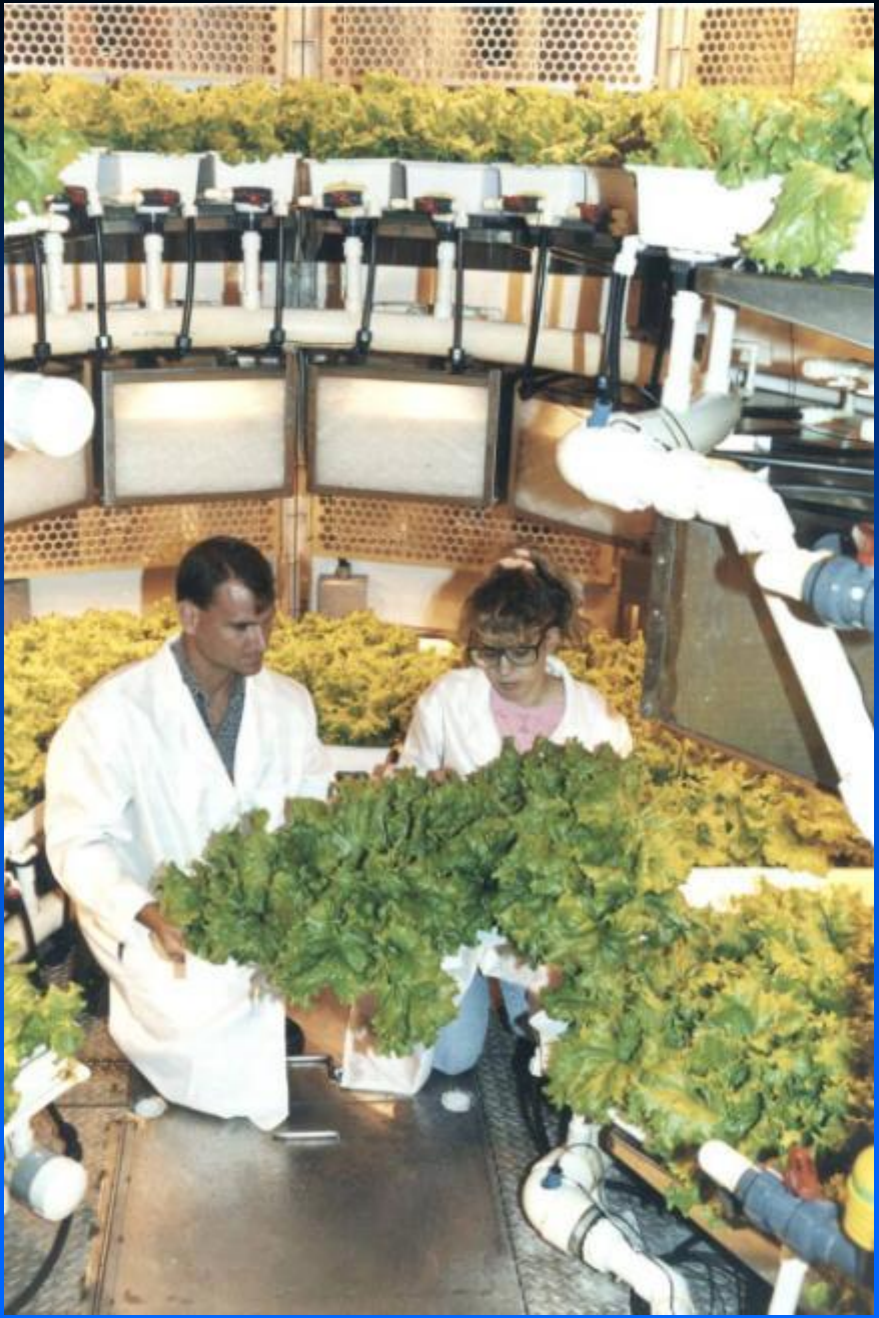
(CH_2O) → Inedible (waste)

For carbohydrate (CH_2O) type crops, Assimilation Quotients (AQs) are ~1.0 (mol CO_2 / mol O_2)
For fat producing crops, AQ's are lower, e.g., 0.8-0.9 (Tako et al., 2010)
Nitrogen, NH_4 vs. NO_3, can also affect AQ, with NO_3, resulting in lower AQs (Bloom et al., 1989)

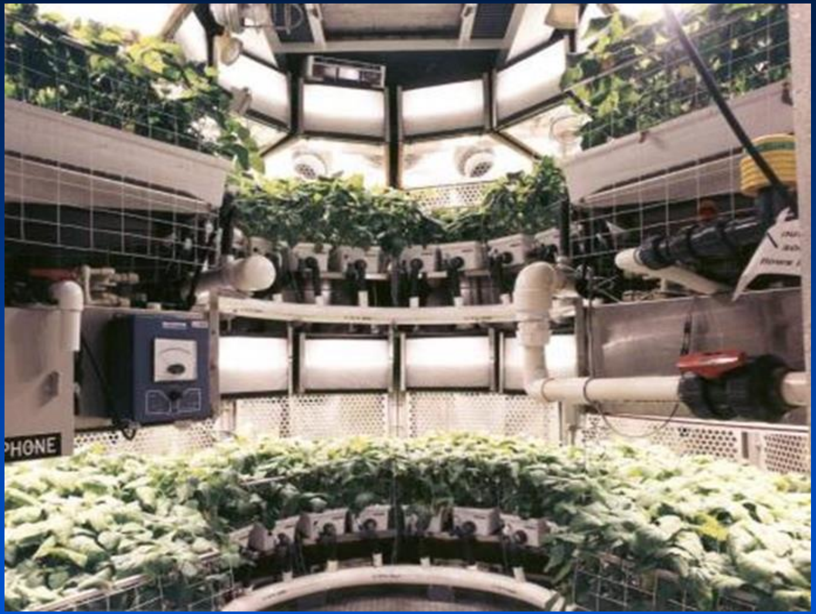
Factors Affecting Plant Photosynthesis and Growth

- Water and Nutrients - Assume these will be optimized
- Temperature - Assume this will be optimized.
- Carbon Dioxide - Optimal range for C_3 crops ~1000 to 2000 ppm (0.1 – 0.2 kPa).
- Light - Will be a primary determinant of plant growth area required.

NASA's Biomass Production Chamber

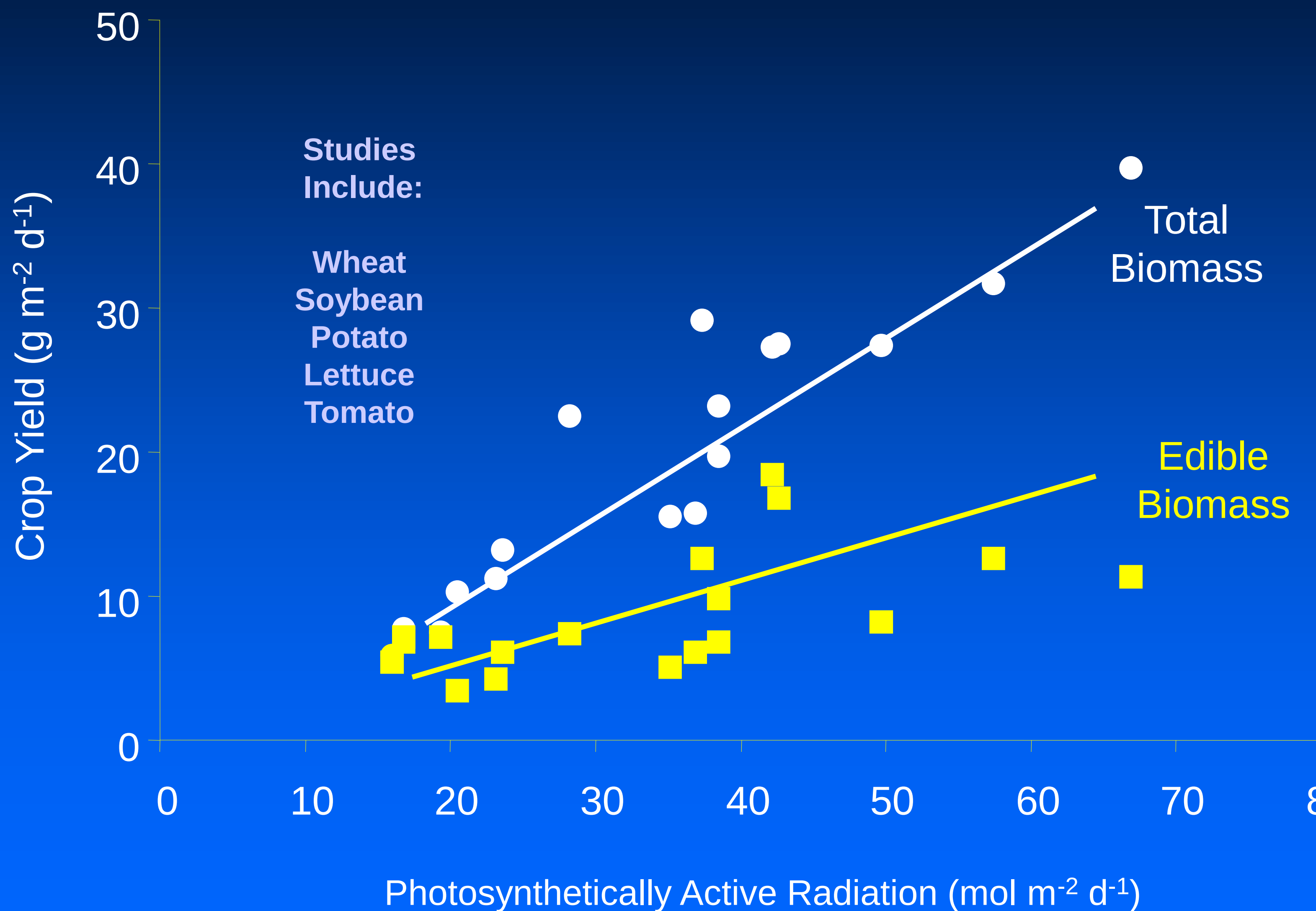


Closed chamber, 20 m^2 area, 113 m^3 vol.



Effect of Light on Crop Yield

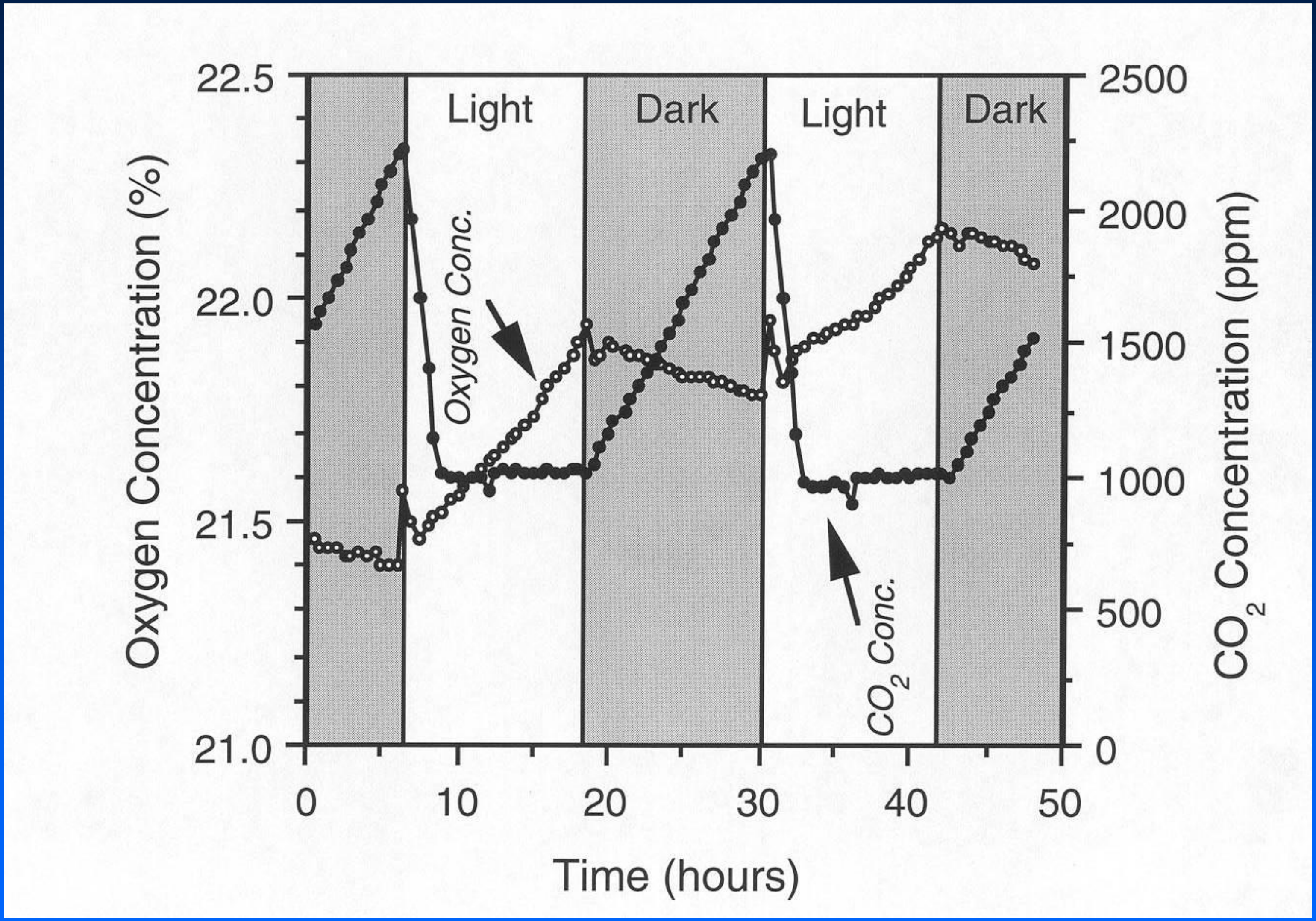
(Data from NASA Biomass Production Chamber)



Wheeler et al. 1996. Adv. Space Res.

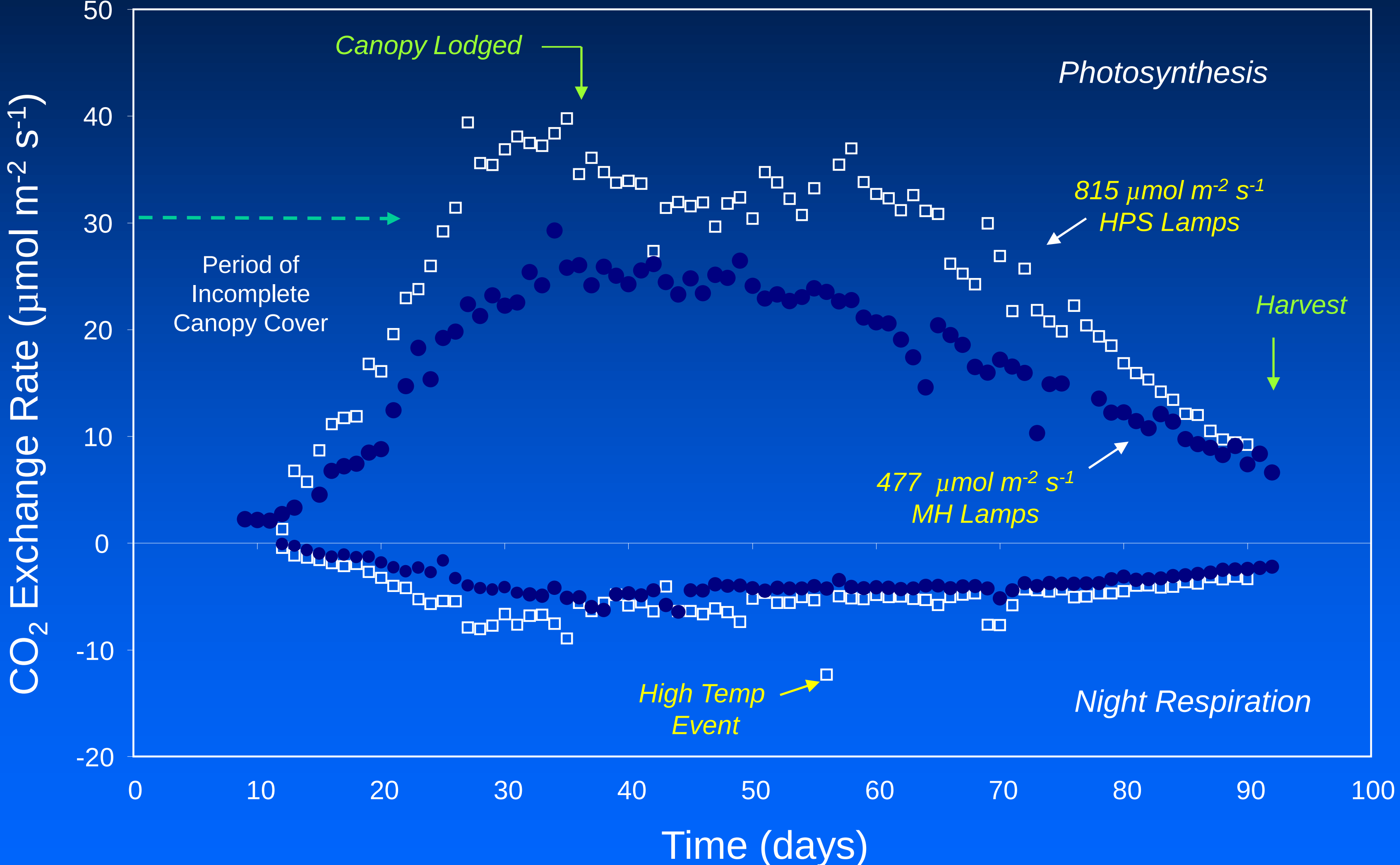
Canopy CO_2 Uptake / O_2 Production

(20 m^2 Soybean Stand)



Wheeler, 1996. Plants in Space Biol. Suge (ed.)

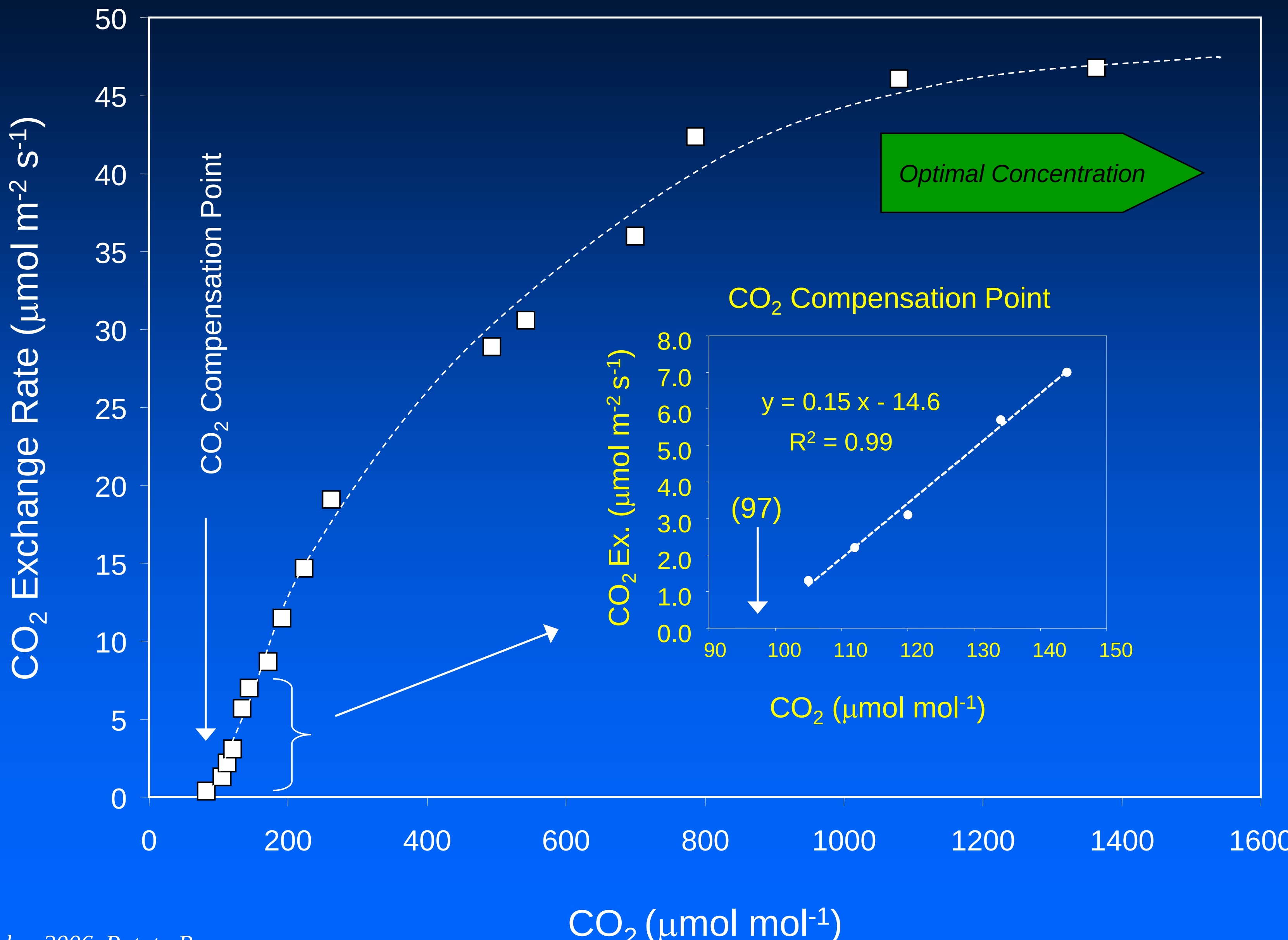
CO_2 Exchange Rates of Soybean Stands



Wheeler et al. 2006. EcoEngineering.

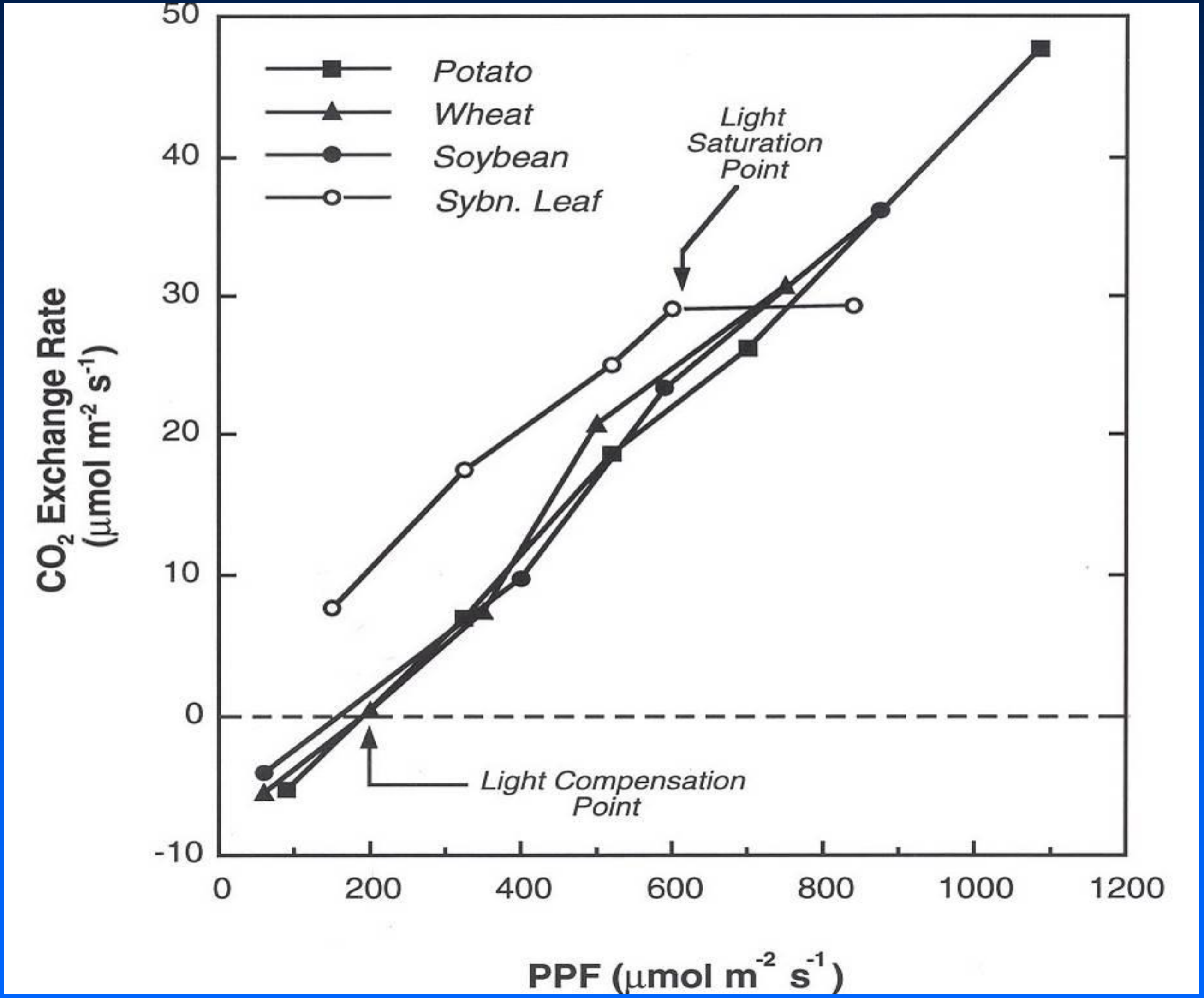
Fig. 6

CO_2 Exchange Rate vs. CO_2 Concentration



Wheeler. 2006. Potato Res.

Effect of Light on Photosynthesis



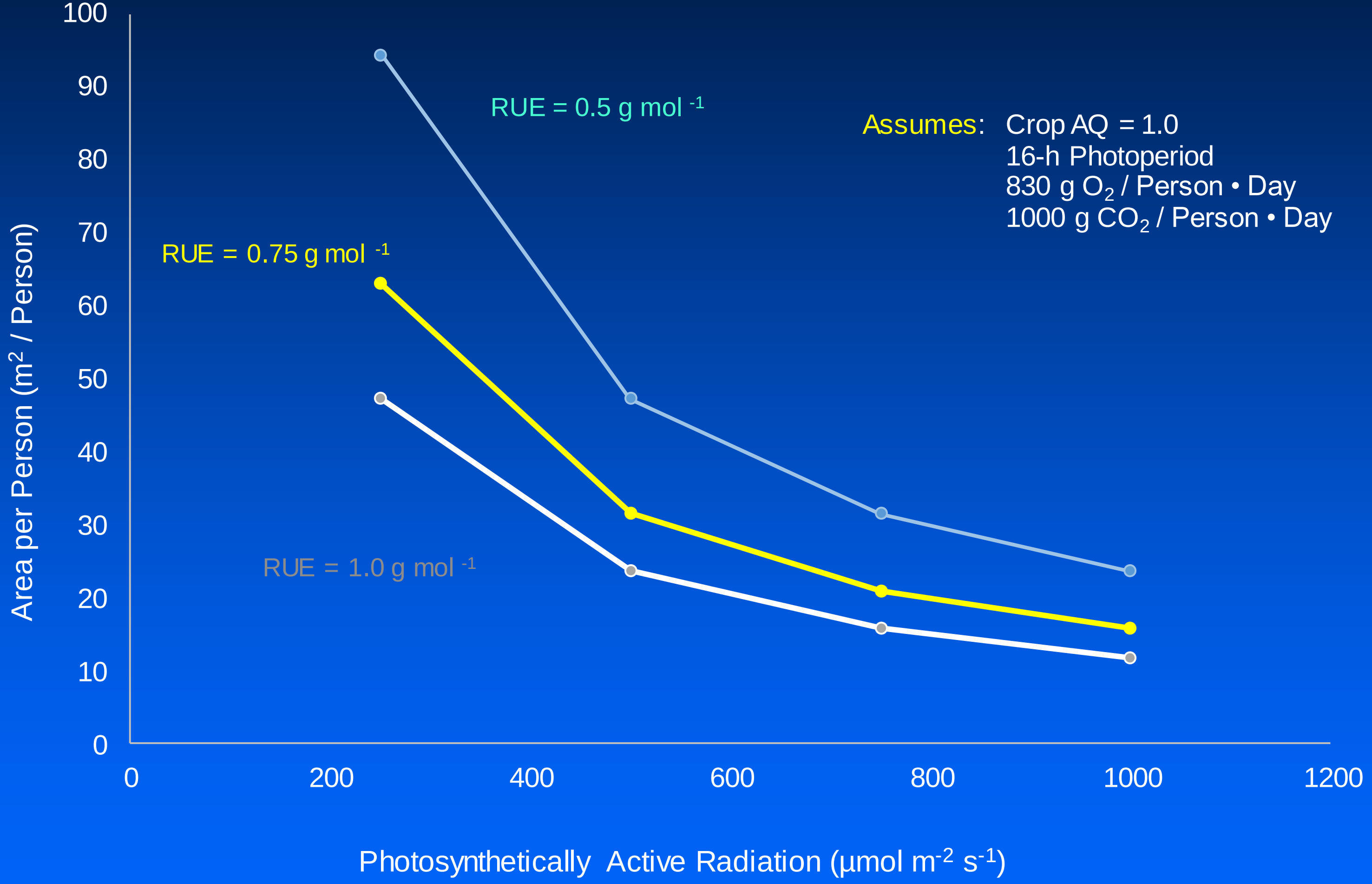
Wheeler, 1996, Plants in Space Biol. Suge (ed.)

Area for CO_2 Removal / O_2 Production for One Person

Radiation Use Efficiency	PPF (µmol m^{-2} s^{-1})	250	500	750	1000
(g mol^{-1} PAR)	Daily Light Integral (mol m^{-2} d^{-1})	14.4	28.8	43.2	57.6
			(m^2 per person)		
0.50		94.4	47.2	31.5	23.6
0.75		63.0	31.5	21.0	15.7
1.00		47.2	23.6	15.7	11.8

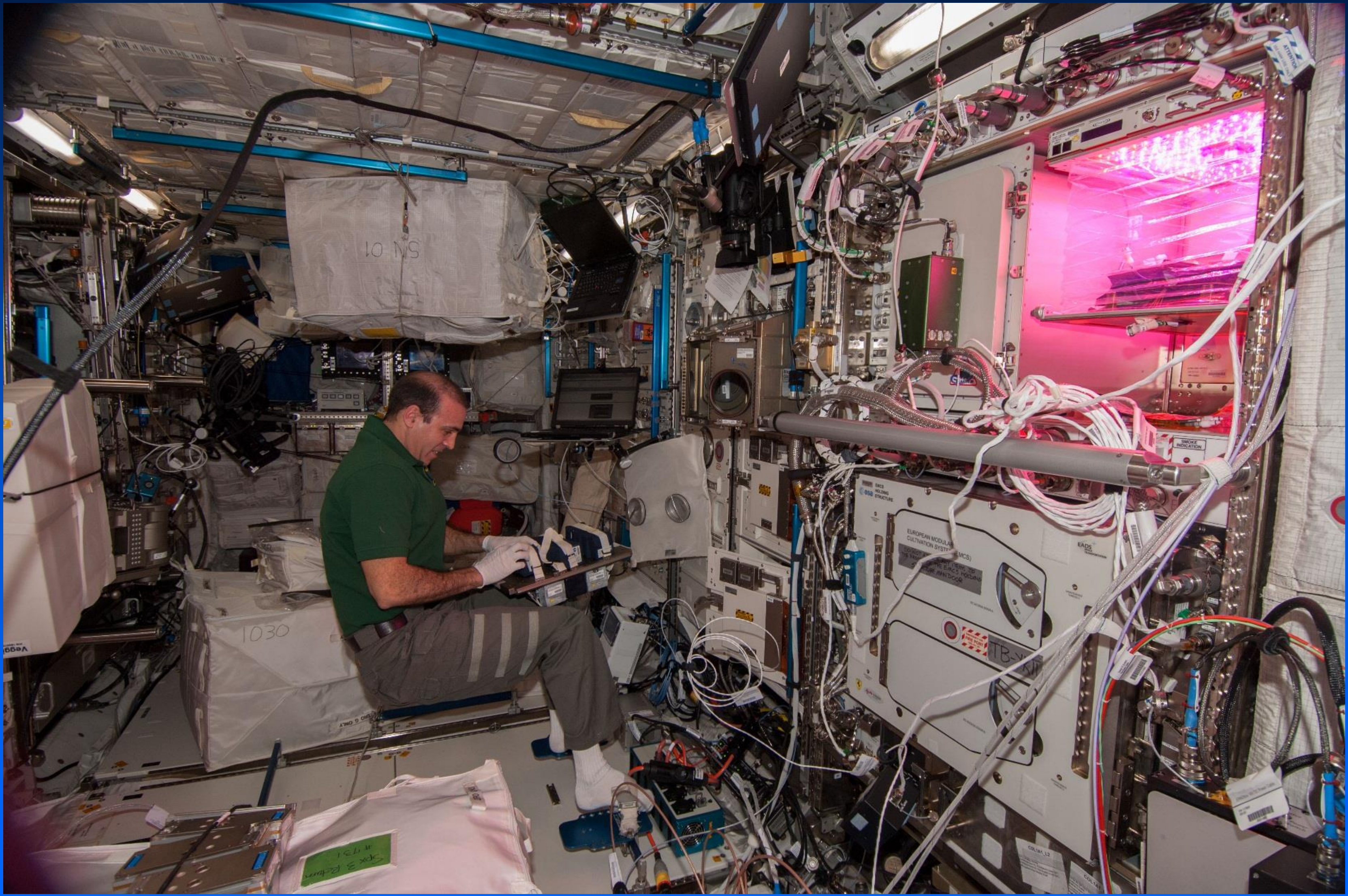
* *Biomass production data assuming Assimilation Quotient or AQ = 1.0 (i.e., biomass all CH_2O)*
** *Assumes daily O_2 requirement of 830 g / person-day (NASA SPP 30262)*
*** *Assumes a 16 h light / 8 h dark photoperiod*
**** *Radiation use efficiency data based on Wheeler et al. 2008. Adv. Space Res.*

Area Per Person for O_2



RUE (Radiation Use Efficiency) Conversions based on Wheeler et al. 2008. Adv. Space Res. 41:706–713 .

VEGGIE Plant Unit on ISS



0.15 m^2 Area

A "Salad Machine" for Space Station and Transit Missions

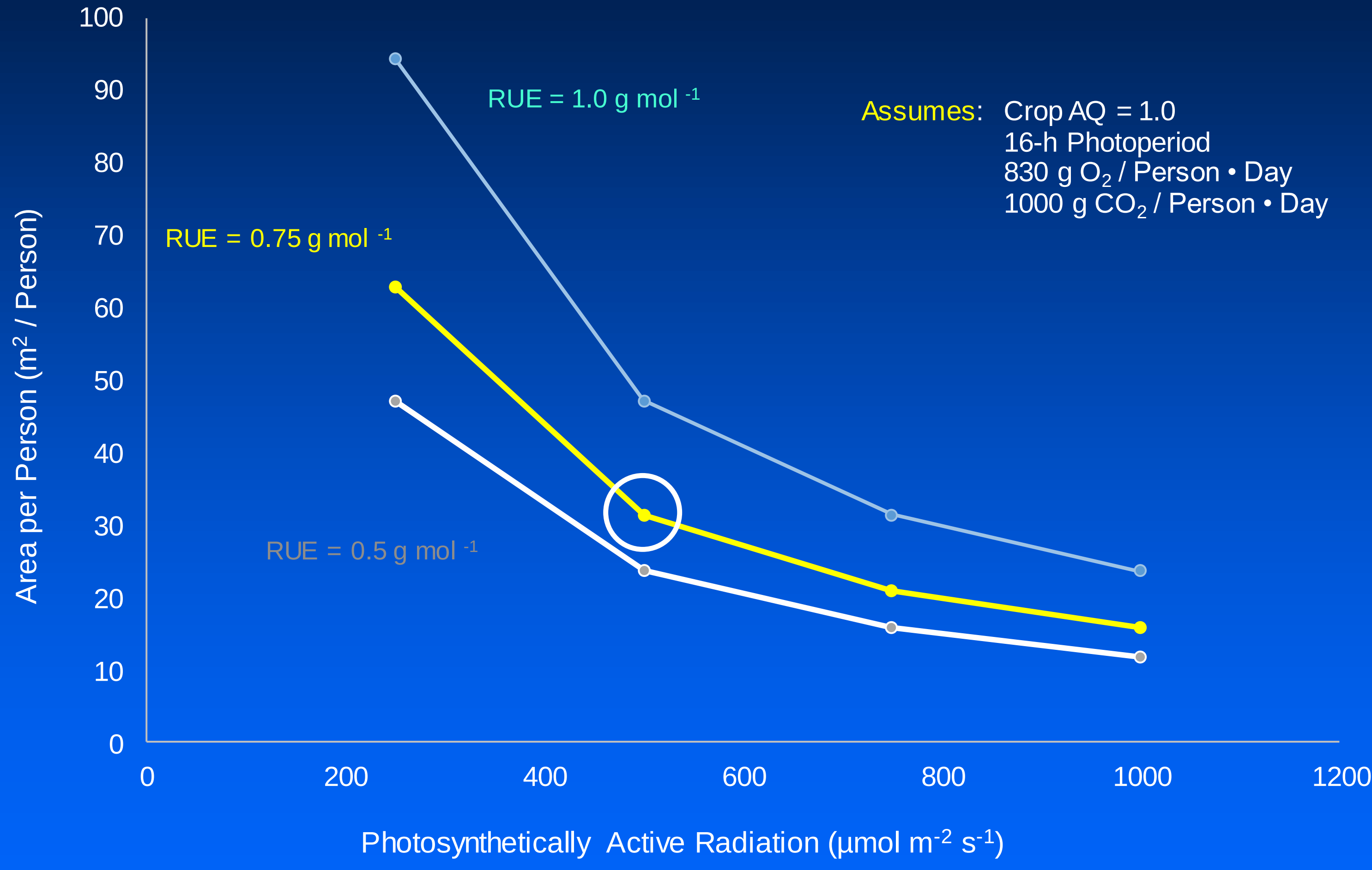
MacElroy et al. 1992. Adv. Space Res.

2.0 m^2 Area

MPLM Type Module for Plant Production ?

10 m^2 Area ?!

Area Per Person for O_2

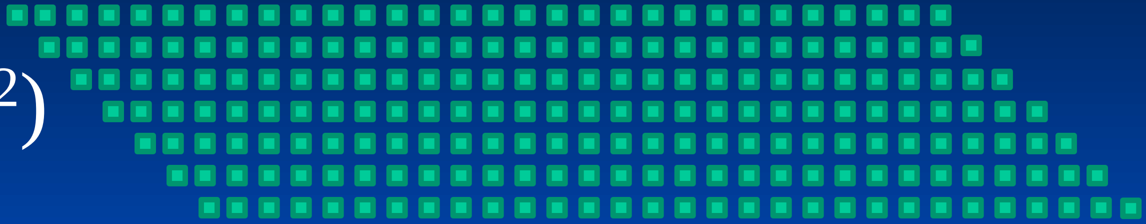


RUE (Radiation Use Efficiency) Conversions based on Wheeler et al. 2008. Adv. Space Res. 41:706–713 .

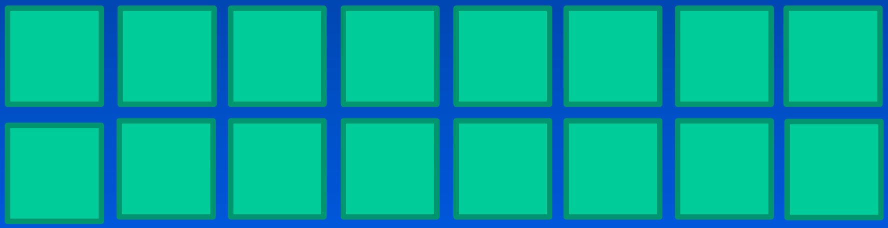
Number of Plant Chambers for One Person's Oxygen

(with 500 µmol m^{-2} s^{-1} PAR and 0.75 RUE)

- VEGGIE (0.15 m^2)
  - → 210



- Salad Machine (2.0 m^2)
  - → 16



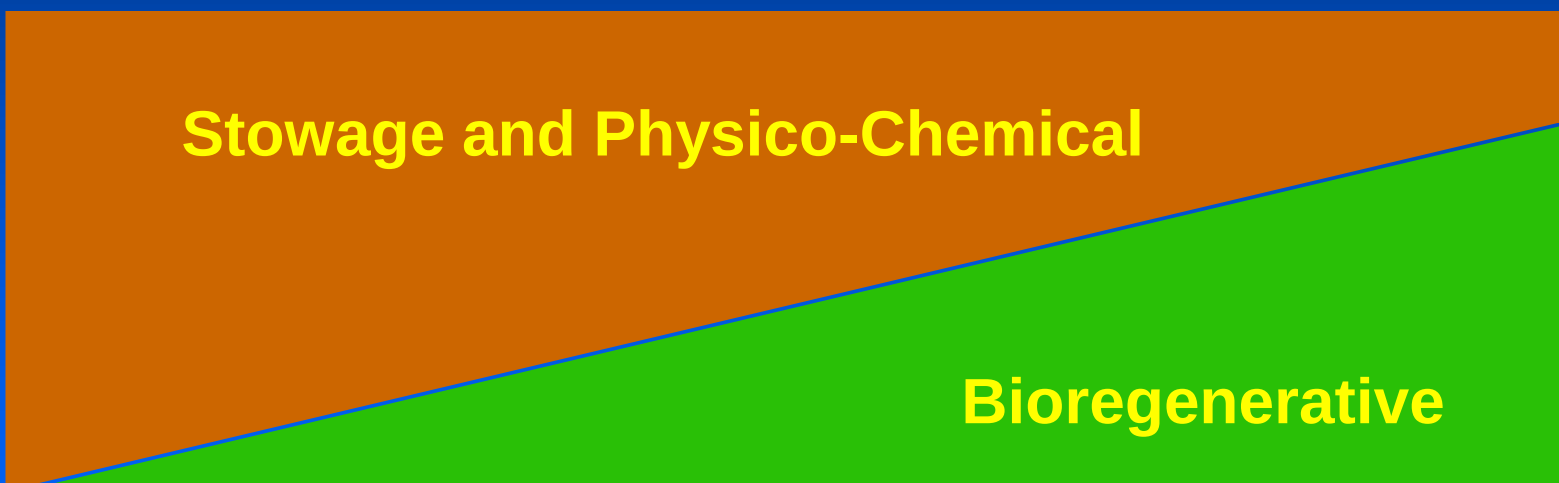
- Plant Module (10 m^2)
  - → 3

One Human's Oxygen from 11 m^2 of Wheat !

Edeen and Barta. 1995. JSC No. 33636

Role of Bioregenerative Components for Future Missions

Short Durations (early missions) | **Longer Durations** | **Autonomous Colonies**



Plant Growing Area →

~1-5 m^2 total | **~10-25 m^2 / person** | **~50 m^2 / person**

Wheeler, 2004. Acta Hort.

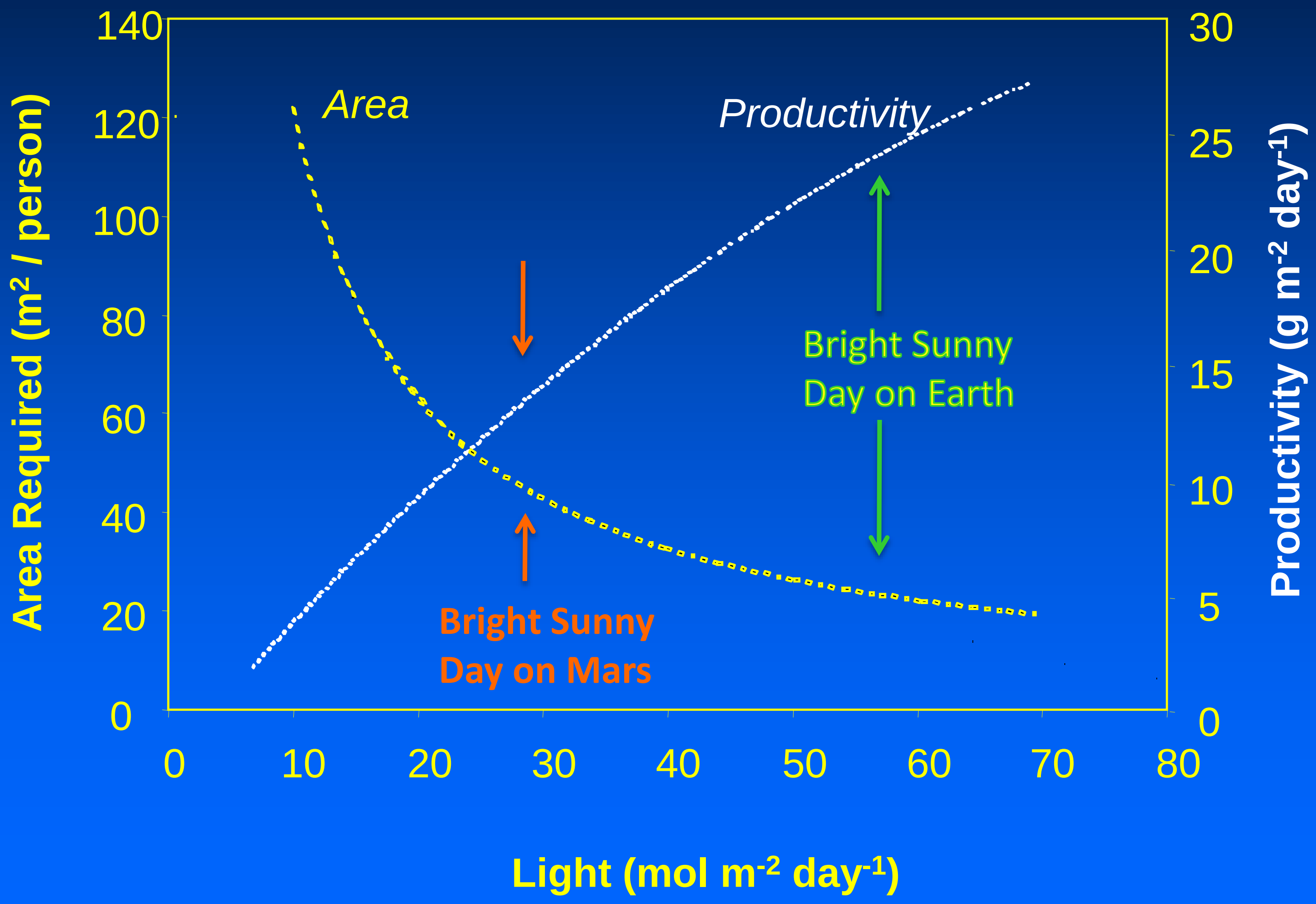
Conclusions

- Bioregenerative life support components will likely expand as mission distances and durations increase.
- Near-term missions can benefit from the production of fresh foods to supplement the crews' diet.
- Contributions of plants to O_2 production and CO_2 removal will be minimal with small, food production systems.
- A plant production module in the range of 10 m^2 could begin to contribute to O_2 production.
- The O_2 production and CO_2 removal by plants is strongly affected by light.
- Radiation (light) use efficiency (RUE) is an important consideration for using plants for life support. Levels up to 1.0 g biomass / mol of photons should be achievable.

Thank You--Grazie!

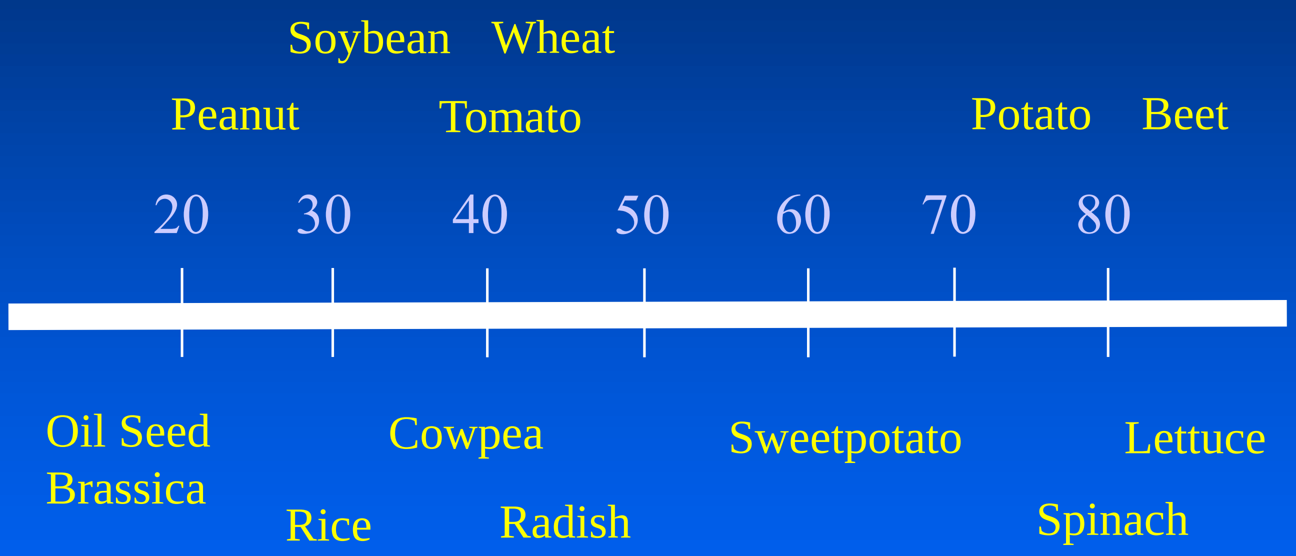
Astronaut Peggy Whitson with Soybeans in Advanced Astroculture Chamber on the ISS

Light, Productivity, and Crop Area Requirements



Harvest Index (%) Ranges for Some Crops*

If inedible biomass recycled aerobically, this will consume some O_2.
Hence high harvest index plants benefit gas exchange for life support



* *Data gathered from controlled environment tests at KSC Breadboard Project and CELSS literature.*

Wheeler, 2004. Acta Hort.