Development of Bioregenerative Life Support for Longer Missions:

When Can Plants Begin to Contribute to Atmospheric Management?

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Plant Photosynthesis

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

(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

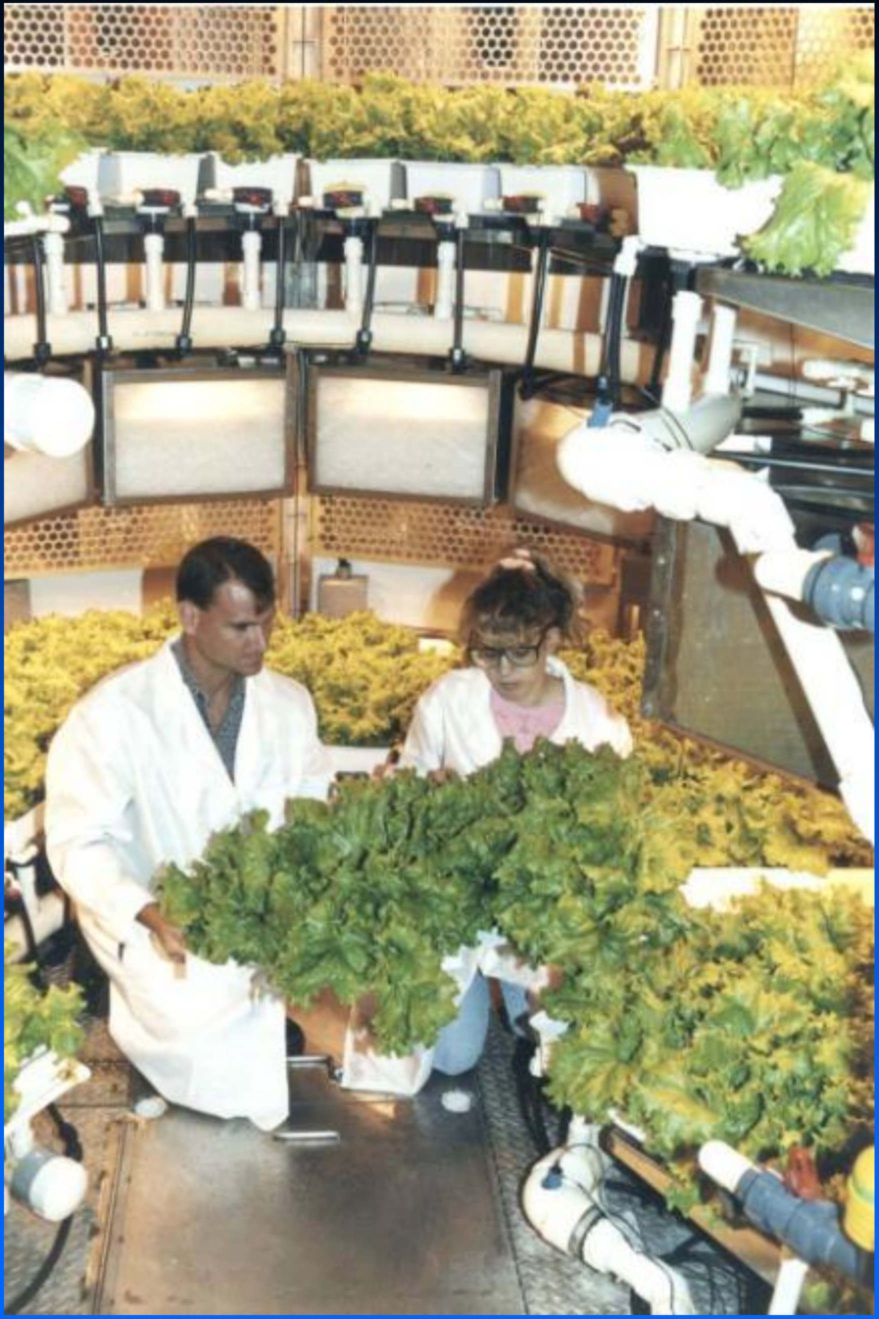
- Water and Nutrients—Assume these will be optimized but there are challenges for micro and reduced gravity settings.

- Temperature—Assume this will be optimized for the given crop species.

- Carbon Dioxide—Optimal range for C_3 crops probably 1000 to 2000 ppm (0.1 – 0.2 kPa); chambers open to cabin air might be exposed to “super-elevated CO_2”, which can cause some problems.

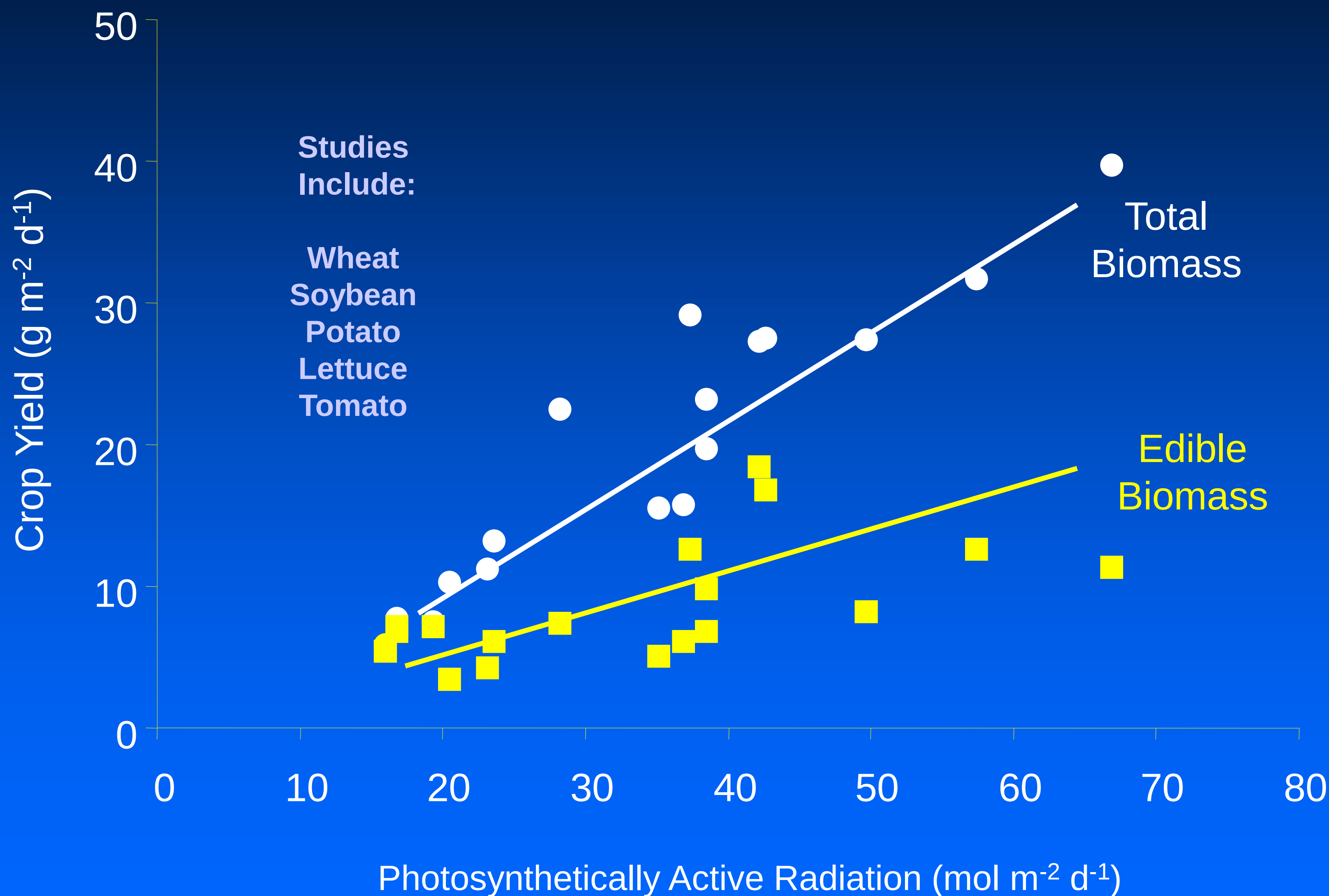
- Light
  1) Light must be intercepted by the leaves or photosynthetic organs. Light on the floors or walls does no good!
  2) Most crops show a linear response of photosynthesis to light across the lower light range.

NASA's Biomass Production Chamber



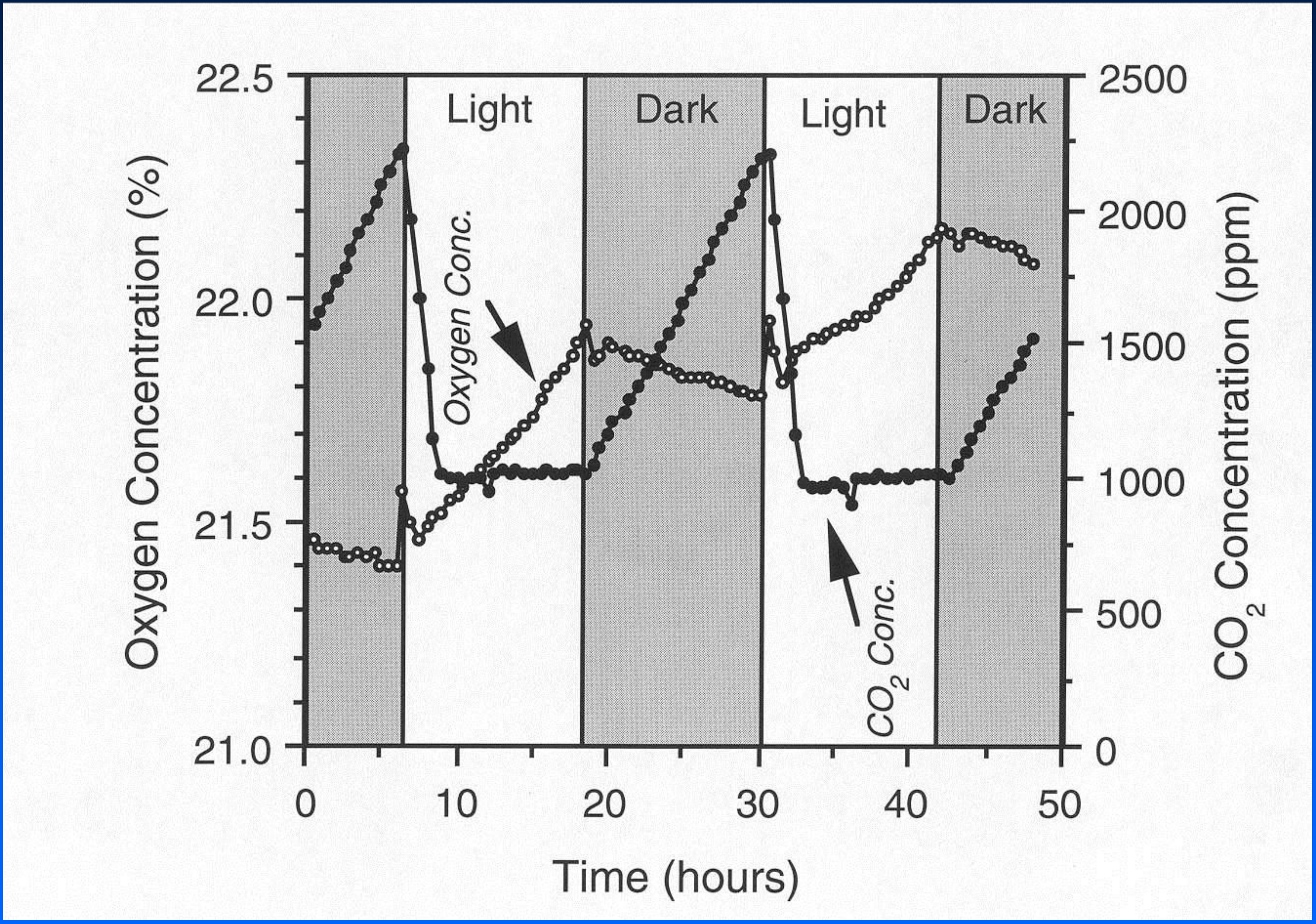
Effect of Light on Crop Yield

(Data from NASA Biomass Production Chamber)



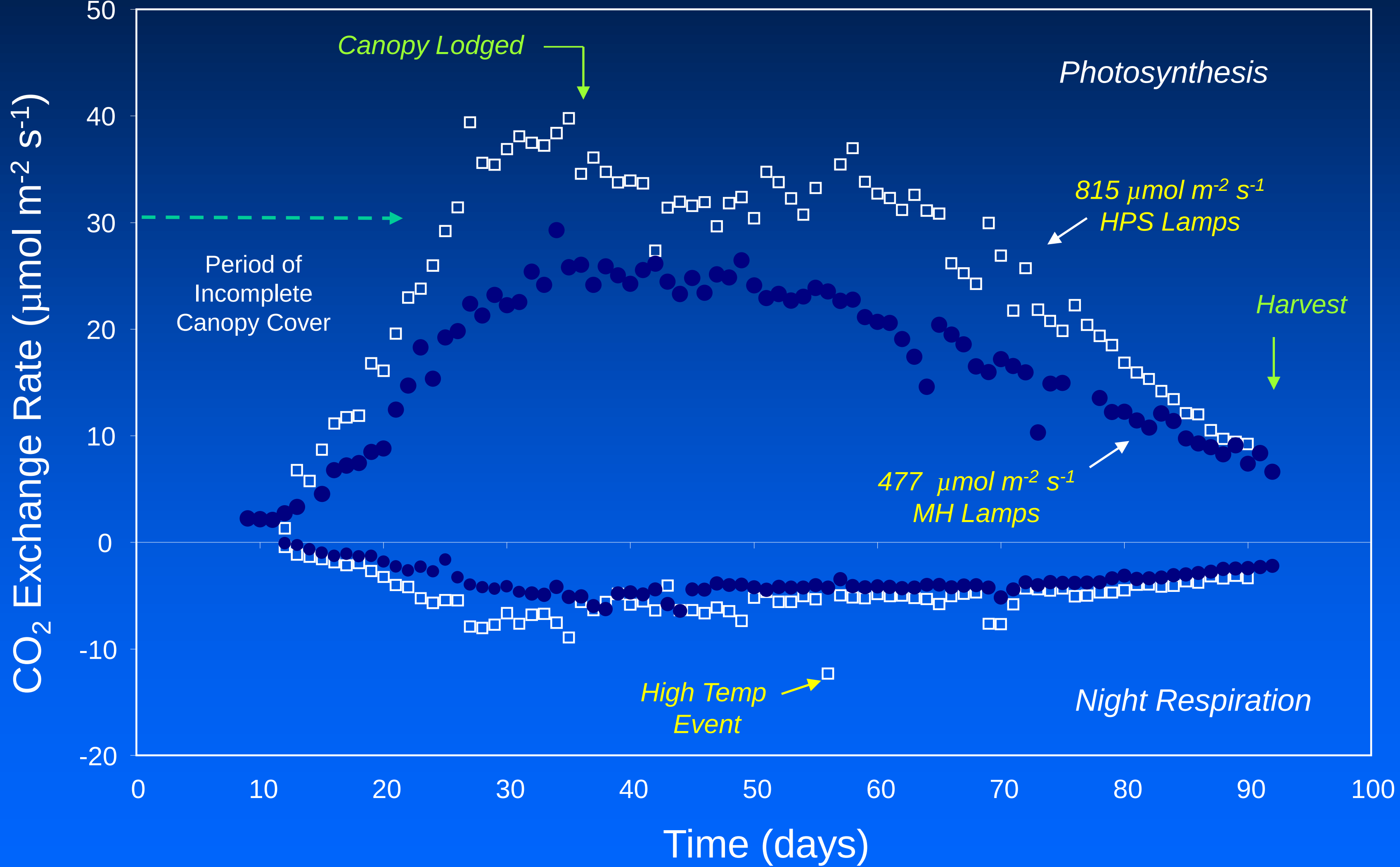
Wheeler et al. 1996. Adv. Space Res.

Canopy CO_2 Uptake / O_2 Production
(20 m^2 Soybean Stand)



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

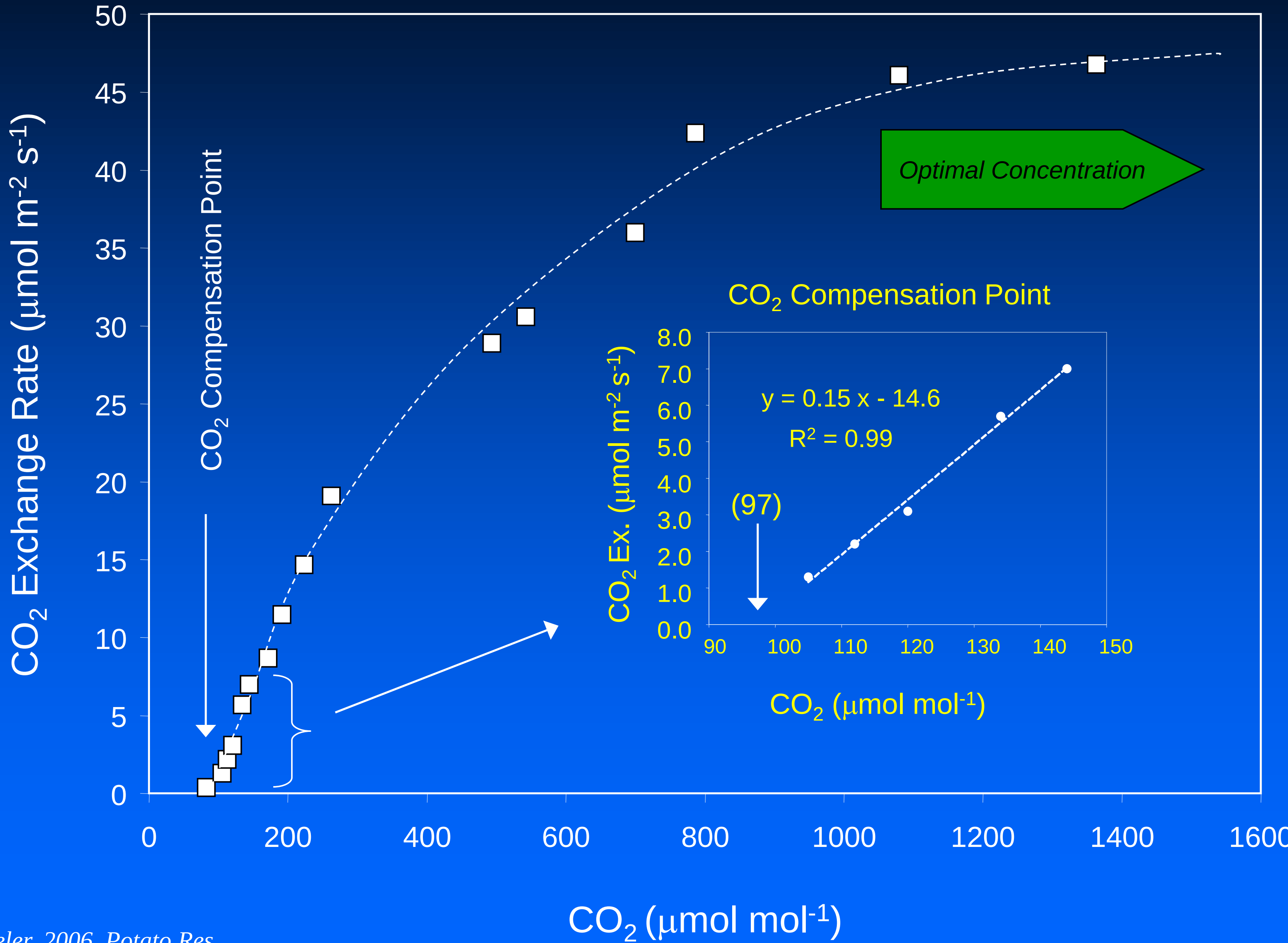
CO_2 Exchange Rates of Soybean Stands



Wheeler et al. 2006. EcoEngineering.

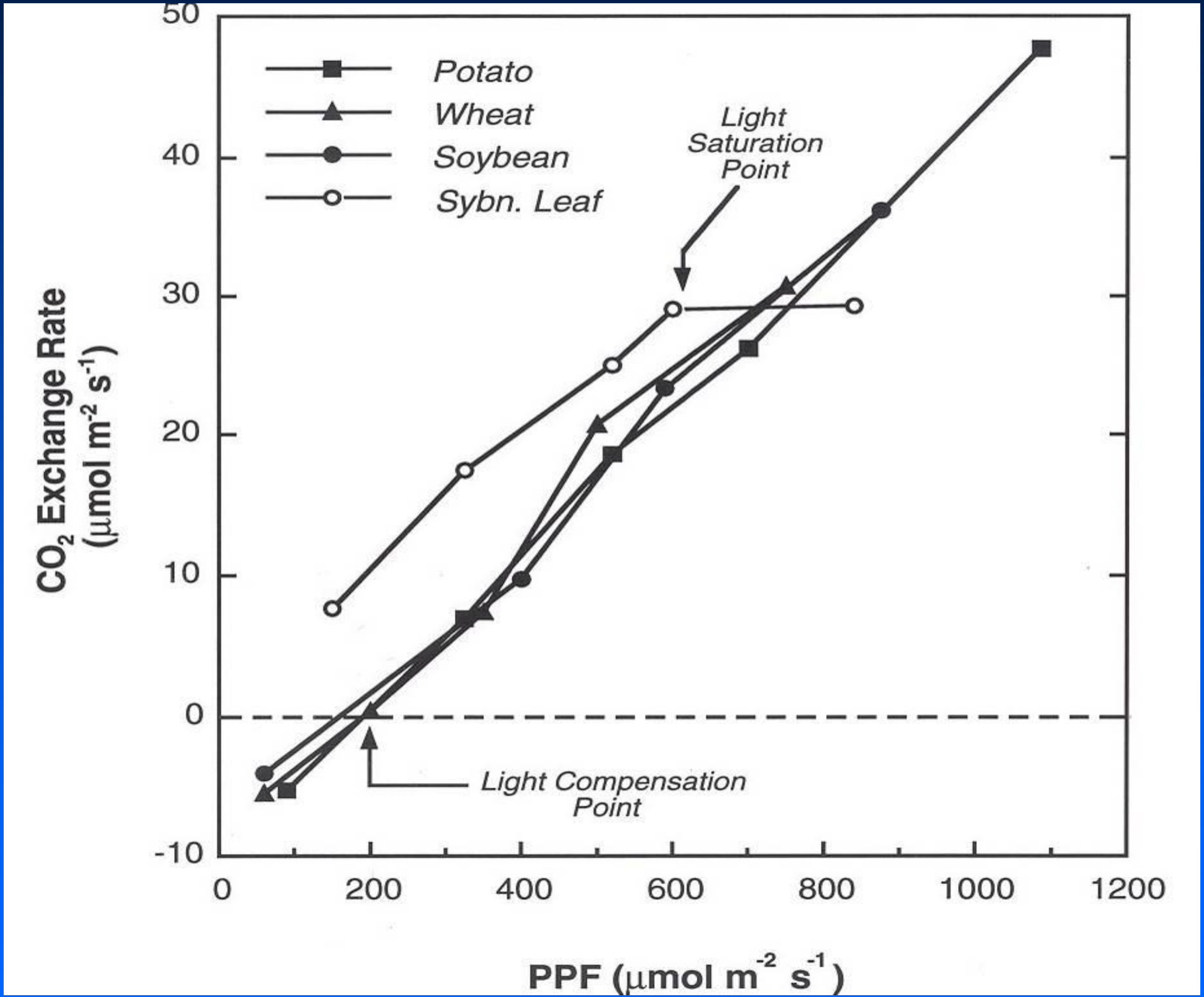
CO_2 Exchange Rate vs. CO_2 Concentration

Fig. 6



Wheeler. 2006. Potato Res.

Effect of Light on Photosynthesis



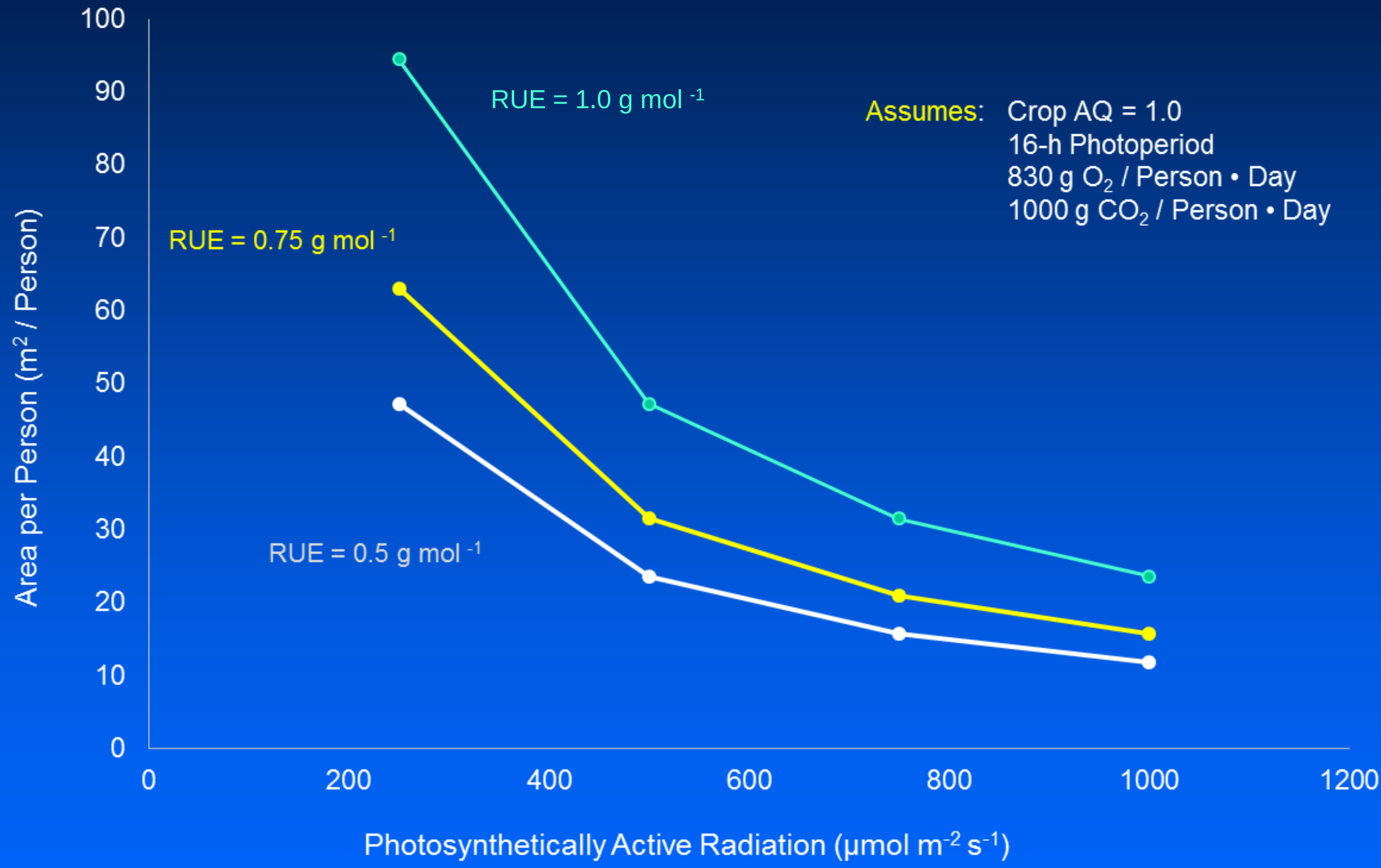
Wheeler, 1996, Plants in Space Biol. Suge (ed.)

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
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 .

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)

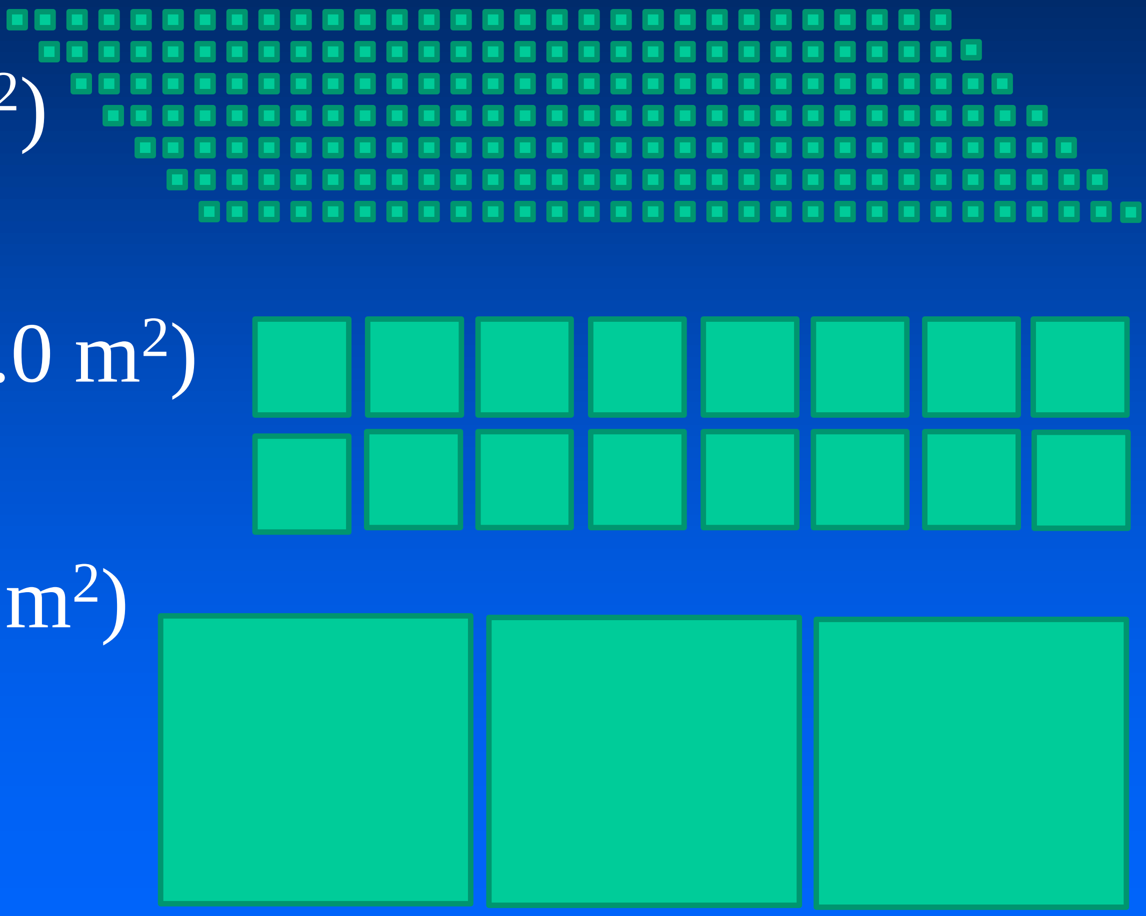
  ➔ 210

- Salad Machine (2.0 m^2)

  ➔ 16

- Plant Module (10 m^2)

  ➔ 3



A "Salad Machine" for Space Station and Transit Missions

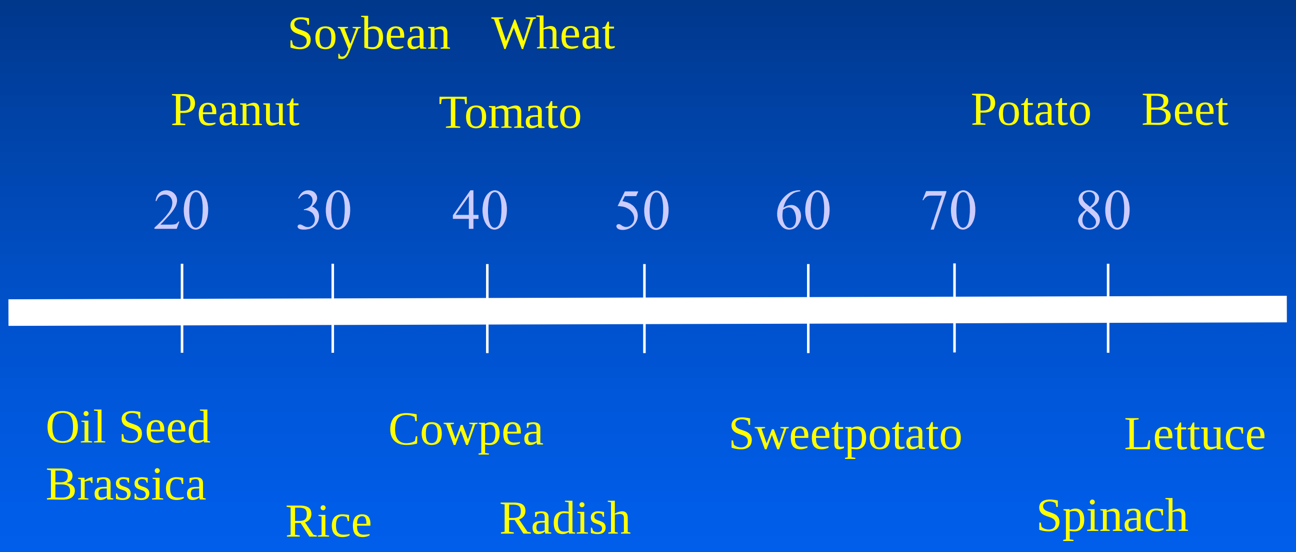
MacElroy et al. 1992. Adv. Space Res.

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

Edeen and Barta. 1995. JSC No. 33636

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

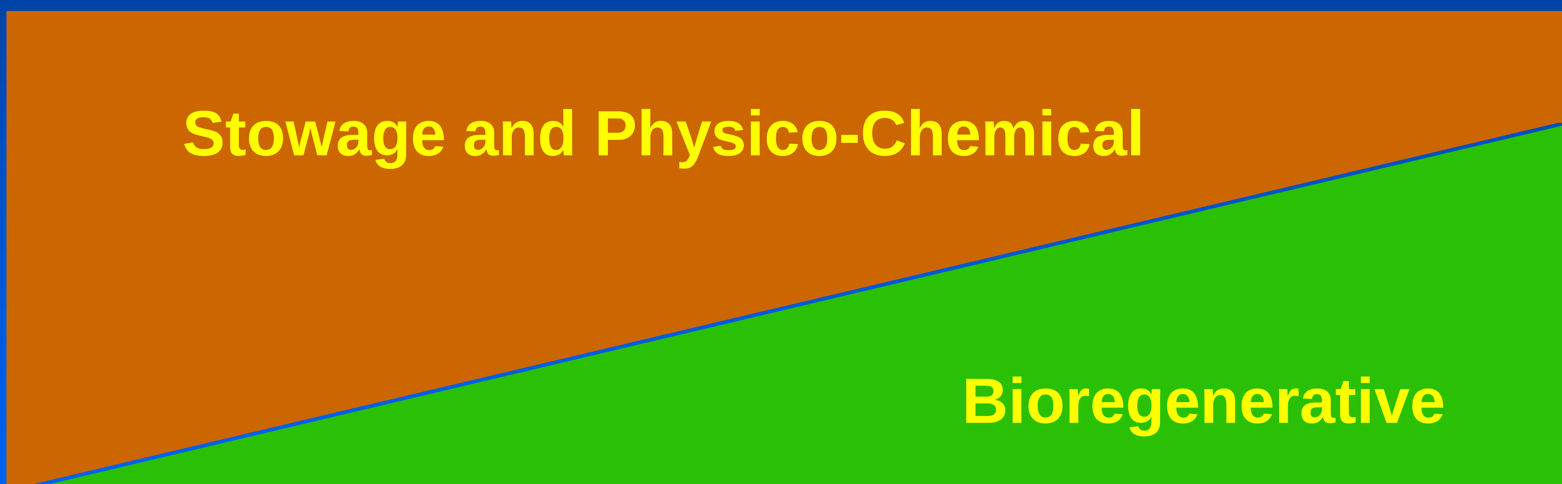


* *Data gathered from controlled environment tests at KSC Breadboard Project and CELSS literature.*

Wheeler, 2004. Acta Hort.

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 aspect to plant performance in future life support systems. Levels up to 1.0 g biomass / mol of photons have been documented and should be achievable.

Thank you!

Astronaut Steve Swanson
Harvesting Lettuce on the ISS

Light, Productivity, and Crop Area Requirements