Moving from Earth to Space: Transferring in use High Density Farming to Space Settlements

NSS ISDC 2022, Space Settlement Track, Regency D, Sunday, May 29 10:00-10:30 am

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NSS NATIONAL SPACE SOCIETY

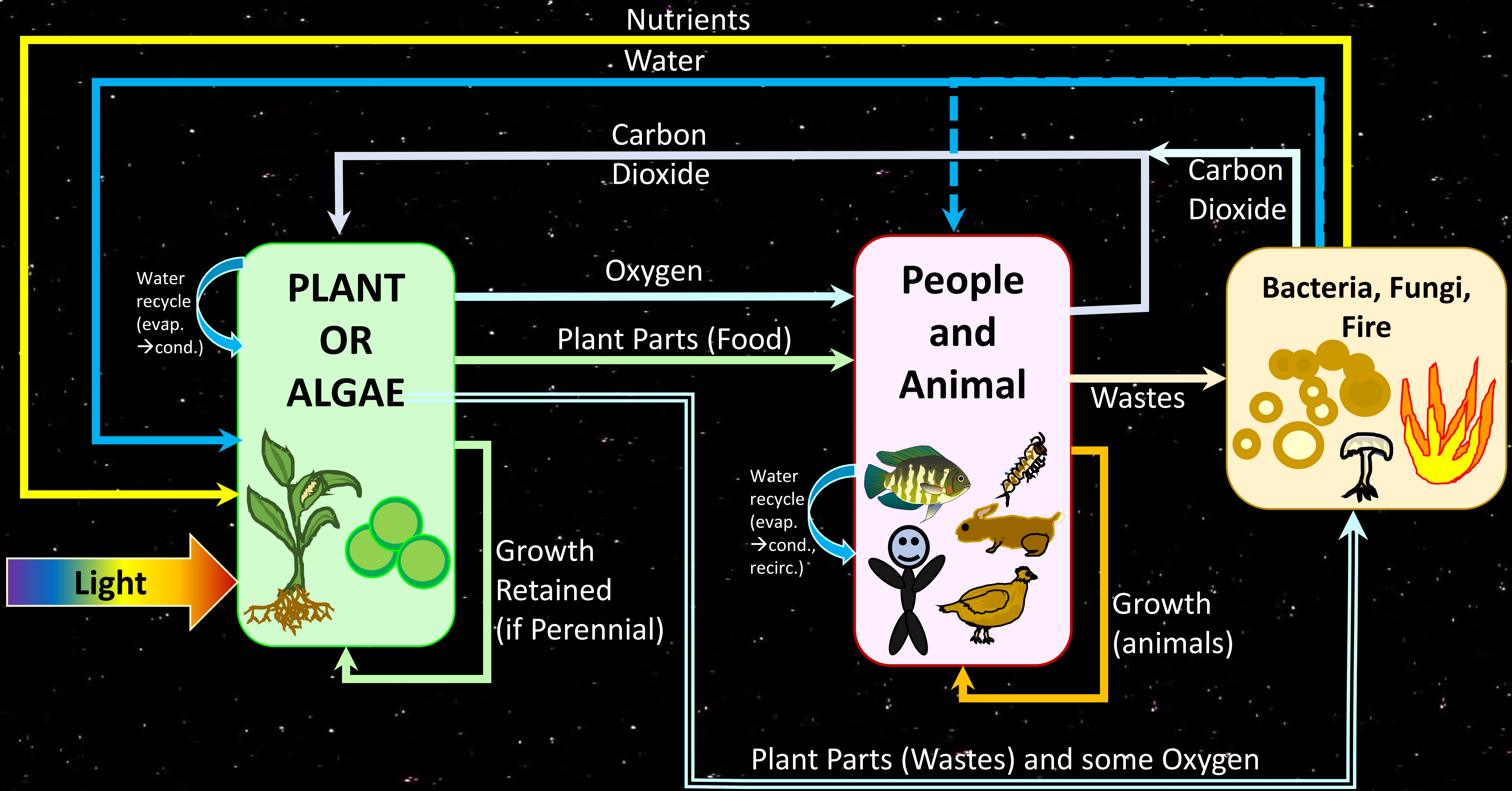
ISDC 2022
International Space Development Conference
Arlington, VA May 27-29

ST. LOUIS SPACE FRONTIER

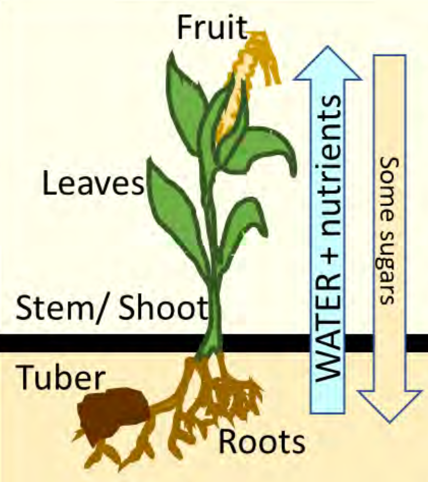
Overview

- Closing (nearly) the space settlement mass flow
- Plant Crop Technologies from Earth
  - High Density Soil Farming now
  - Vertical Farms, Soilless Farms Here
  - State of the Art Tech: Lighting, Vertical and Soil/Soiless Tech, Sensor-Response Systems, Fertilizers

Simplified Space Settlement Mass Cycle



(Vascular) Plant 101

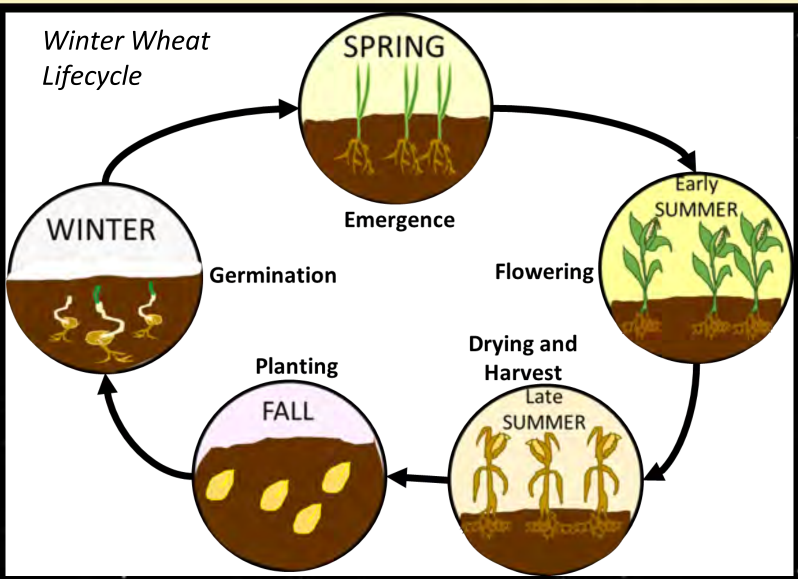


Green Parts:

- Need light
- Need CO_2 from air
- Evaporate water to air
- Pull water and nutrients from roots
- Send some sugars to roots

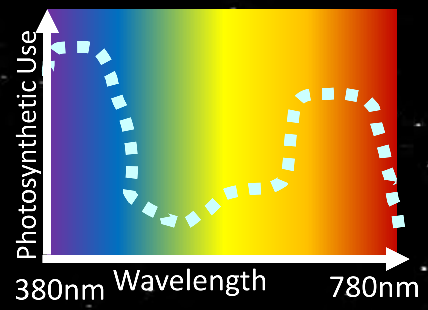
Root/Ground Part:

- Need some oxygen
- Need water and nutrients
- Need sugars, have bacteria and fungi



Plants and Algae are essentially **carbon dioxide + water**, with a few nutrients

Light (spectrum based on species and timing)



Air w/CO_2 concentration (Earth:~0.042%)

Transpiration (**water** evaporation based on relative humidity)

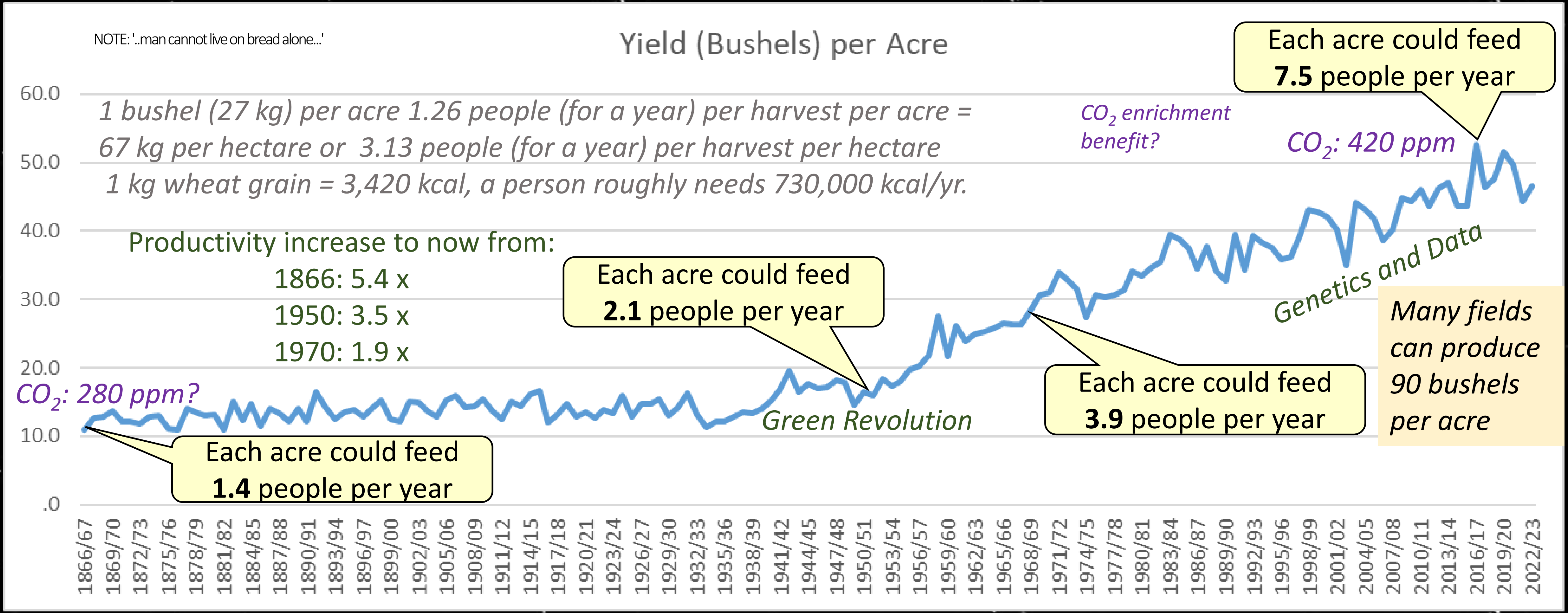
Water, Oxygen, Minerals, **Nitrogen-rich Nutrients**

Modern Fields on Earth

- Productivity per acre is 3+ times greater than in 1950s
- Field crops are planted very close together…too tight to walk between rows easily
- Grain crops are hybrids of dwarf species: High percentage of grain/fruit to stem/leaves/roots. GMO or no.
  - Wheat plant mass at harvest is >43% grain.
- Chemically intensive: Nutrients (anhydrous ammonia, urea) and insect/fungi/weed controls

Fields near Winfield MO USA, Aug 2017

Productivity per area: Wheat in Fields, USA



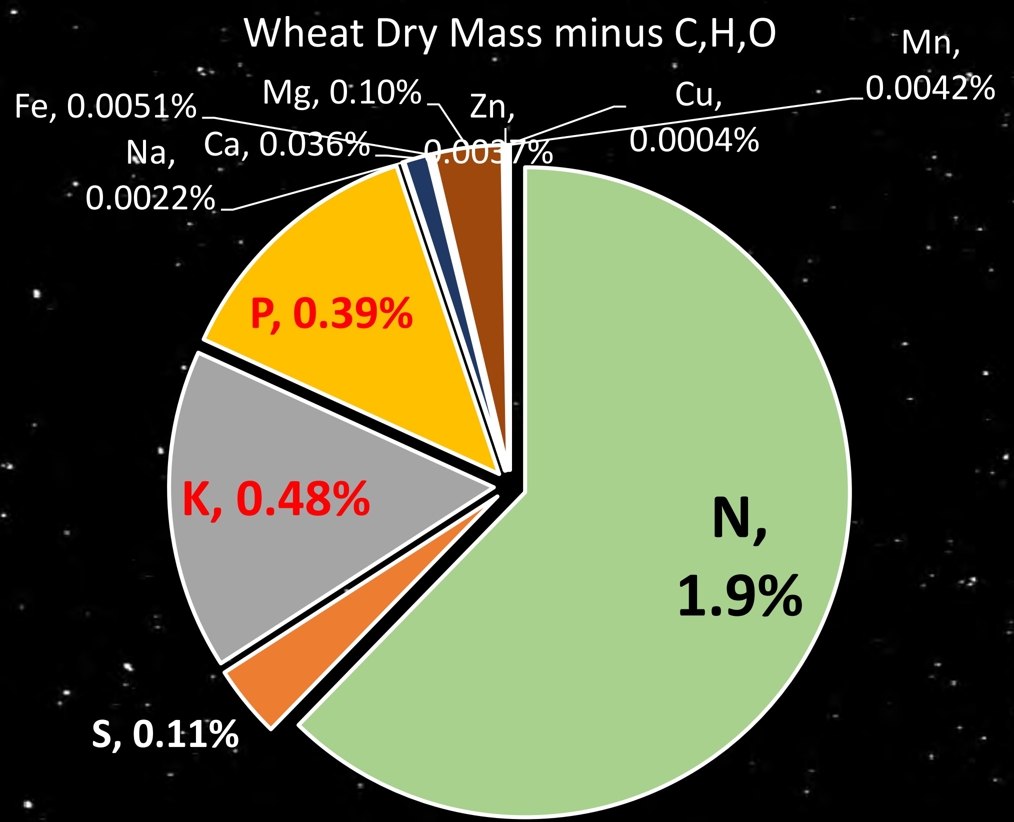
- Raw Data via: Economic Research Service, U.S. DEPARTMENT OF AGRICULTURE: https://www.ers.usda.gov/data-products/wheat-data/
- Atmospheric Carbon Dioxide Concentrations: NASA: https://svs.gsfc.nasa.gov/4962

Data and Genetics in Fields

- Data is one of the most powerful methods to improve yields: fine grained tuning of where to water, where to fertilize, what to plant, and how to plant and control tightly (using lasers, GPS) Chlorophyll sensing is big!
- Complex modelling of microclimates in fields, plant responses to variables based on genetics, lab data, historical data.
- Tuning breeds and varieties based on microclimates and weather projections.
- Genetics targeted to maximize yields for market with minimal inputs. **Will need varieties for various space settlements**.
- Trade: genetics for today (w/hybrid breakdown) vs. heirloom for space
- Highly targeted chemistry based on specific genetics and conditions.
- Trade: healthy soil vs. high production this year

Fertilizer…what and why

- Fertilizers injected directly into the soil (gas, liquid, pellets), **wrapped around seeds**, and **specifically targeted to individual plants based on data**.
- Varies by crop…Legumes/beans need far more nitrogen than wheat
- Common (Soil) Fertilizers: (Anhydrous Ammonia) NH_3, (Urea) $CO(NH_2)_2$
- Mineral supplements, usually in carbonate, oxides, or salts: **in hydroponics/aeroponics a must use**
- In soils or substrates, fertilizer might be feed for the soil biome and plant together…especially manure, ash, tilled silage, etc.
- Too much fertilizer: chemical burning of roots, misbalance of bacteria/fungi.
- **Hard to balance in substrate-less/hydroponic growing:** Need tight sensor-valve control as in current hydroponics software
- Salts must be carefully managed also, which is why undiluted urine is not used, or why over time salts accumulate in soils (esp. near Indio, CA).



Calculated roughly from data in [USDA FoodData Central]

*On Earth, **1 hectare of wheat** in soil usually gets >96 kg of urea or >56 kg in ammonia in fertilizer, of which at most 85% is absorbed by the plant (some say 65%). If the soil is mineral poor (or hydroponic) add up to 100 kg mineral additives (inc. P, K, S, etc. in bioavailable forms)*

Industrial Hydroponic Tech

- Moving Floating box: Common for salad greens: sprouts in floating containers move slowly in trays of solution under lights for a week to maturity at end.
- Deep water: Floating containers in troughs or buckets of oxygenated solution
- Shallow water: Roots sit with supports in solution
- Sleeve: pioneered by U of AZ (and Dr. Ray Wheeler) see diagram in later slide
- Aeroponics: Spray in chamber over roots
- Substrate: Hydroponics can have substrates or not.
- Diaper: As in ISS, fiber substrate around roots, fed by drip line.

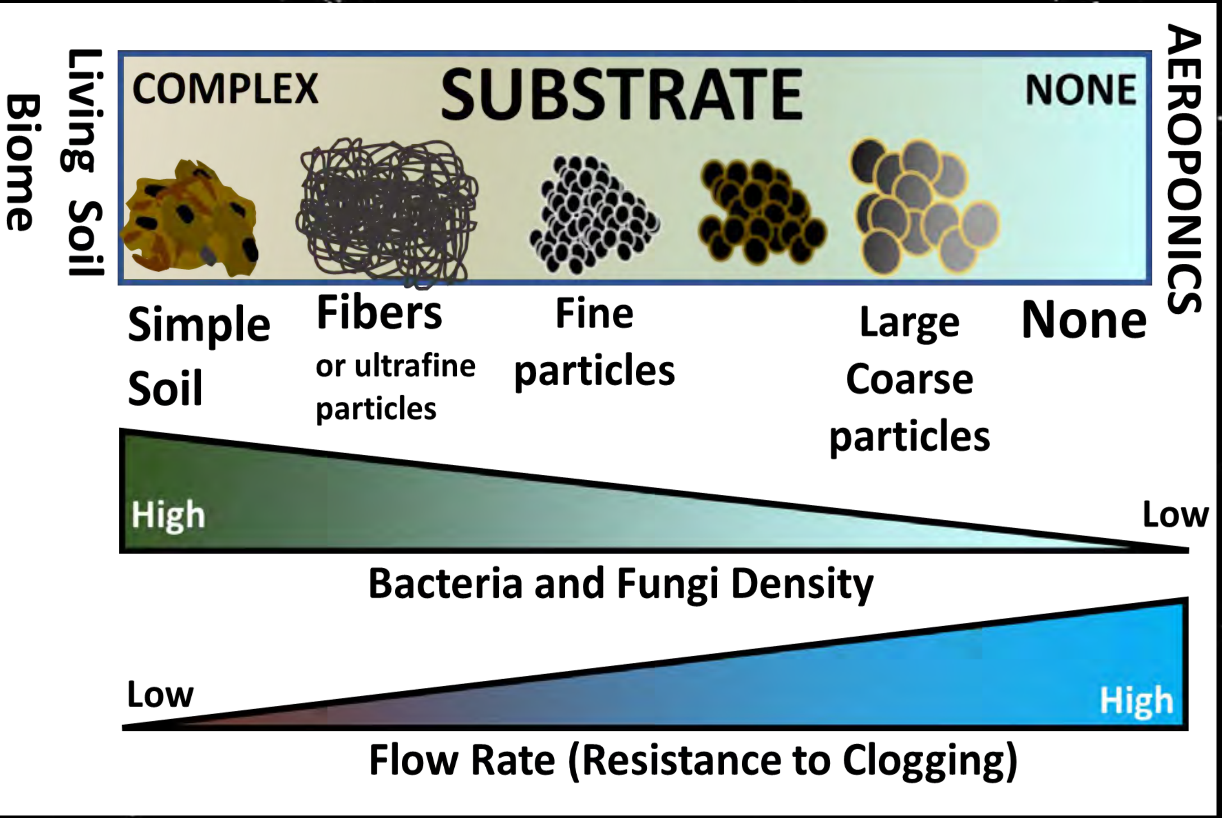
NAAVA green wall picture by author from a hotel in Las Vegas NV. See: https://www.naava.io/en/

Vertical Farming on Earth

(middle) Image Number D4686-1, Photo by James Altland, USDA-ARS found at: https://www.ars.usda.gov/oc/images/photos/aug21/d4686-1/
(left) Image Number D4685-1,Photo by Kai-Shu Ling, D4685-1, USDA-ARS found at: https://www.ars.usda.gov/oc/images/photos/aug21/d4685-1/
(right) Image Number D4687-1,Photo by James Altland, USDA-ARS, found at: https://www.ars.usda.gov/oc/images/photos/aug21/d4687-1/

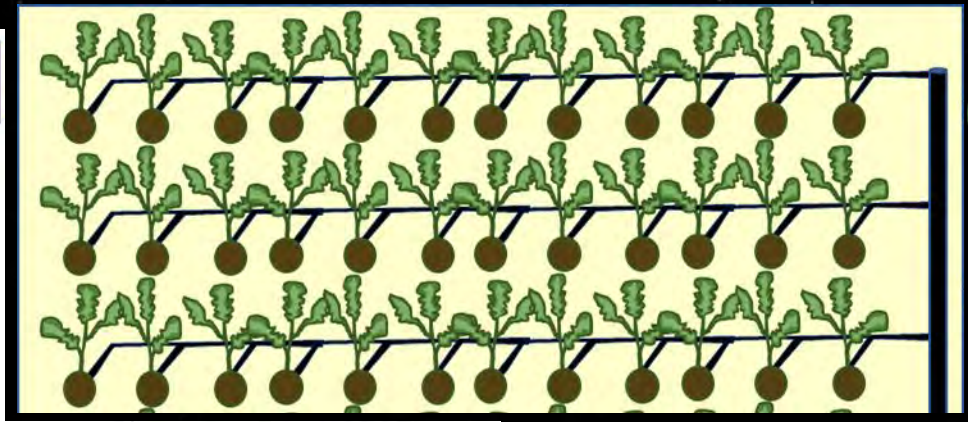
Soil or No Soil?

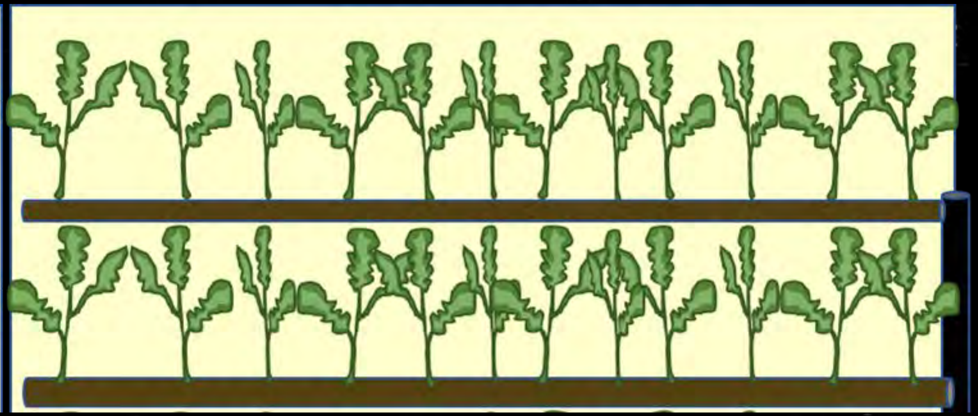
- Natural Earth soil is a complex ecosystem of bacteria, fungi, and invertebrates mixed with bits of decaying plant and animal matter, minerals, and other particles of various sizes.
  - Soil can be considered a mostly aerobic organism since it takes in oxygen, releases CO_2 and Water.
- Soil can be made from regolith over time, using chemical processes, and by adding wastes from plants and people. **Will need mother soil.**
- Hydroponics and Aeroponics are faster to set-up, with less mass, but require tighter chemical control
- The right bacteria and fungi, can **chemically buffer roots even w/o soil**. **Will need to bring cultures!**

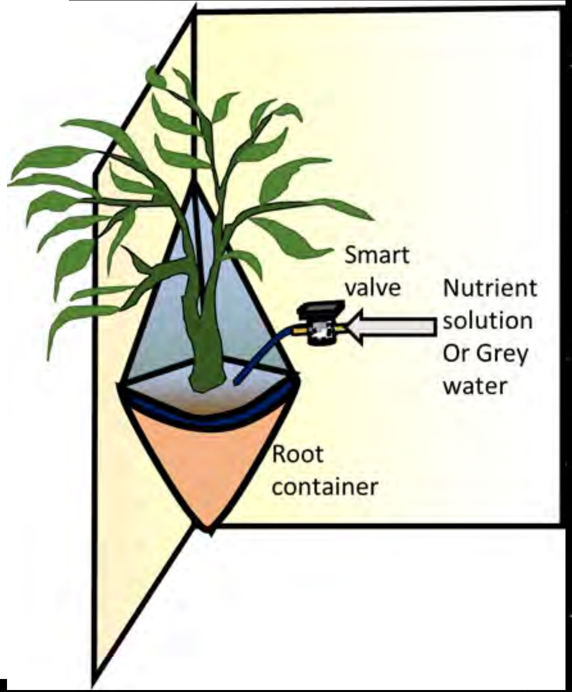


Various versions for vertical farms on Earth use everything from simple substrates like pellets or pebbles, to no substrate.

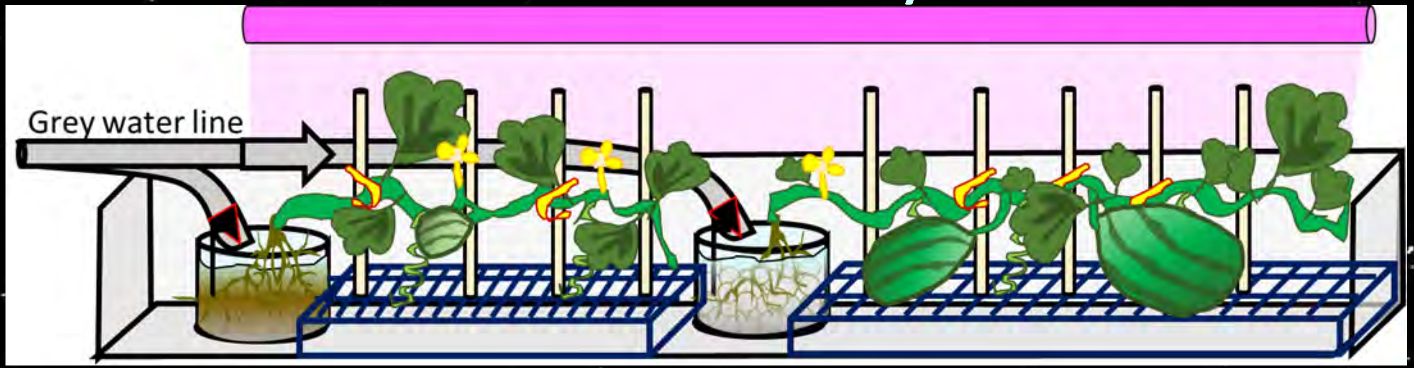
Taking advantage of tight spaces





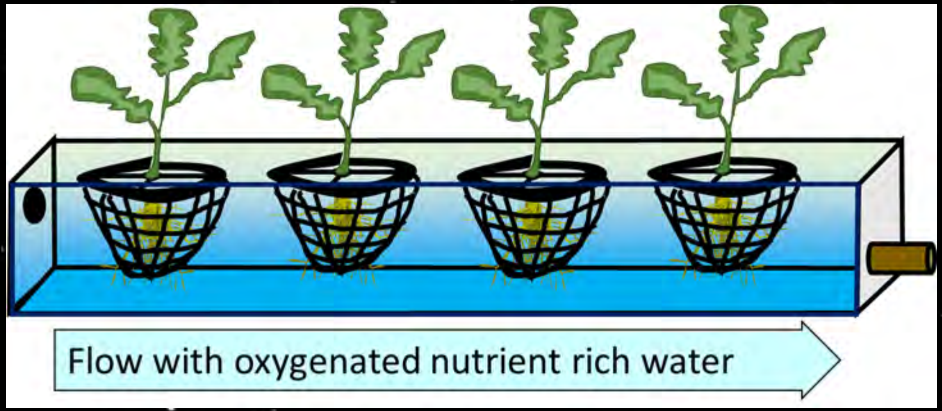


Any corner, column, or hallway can be a grow area, using grey water from various uses. Smart control of drip to root balls is critical. Water from transpiration is condensed and sterilized for clean water for humans.
Will also clean air in settlements. **Already in use on Earth.**

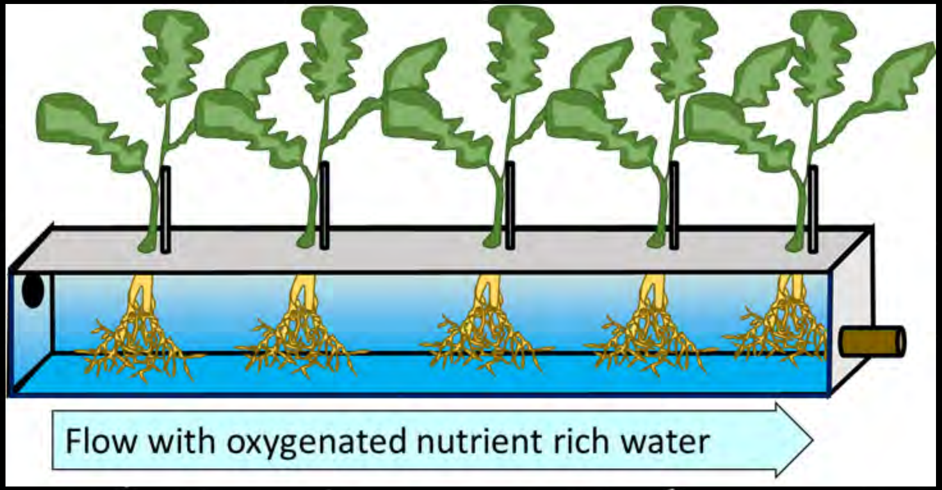


A few schematics for hydroponics

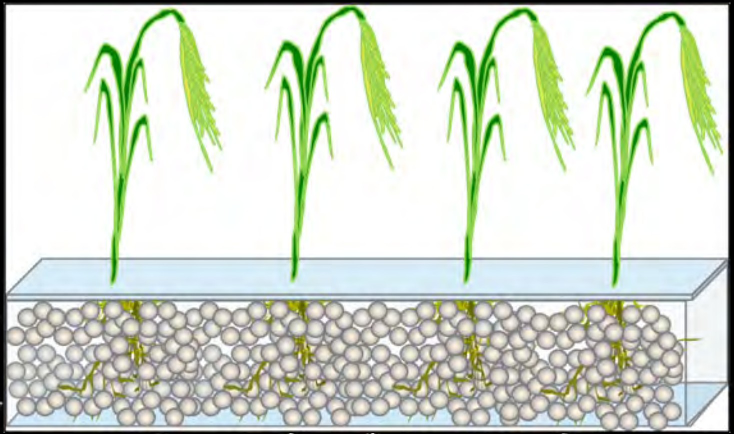
Floating Tray



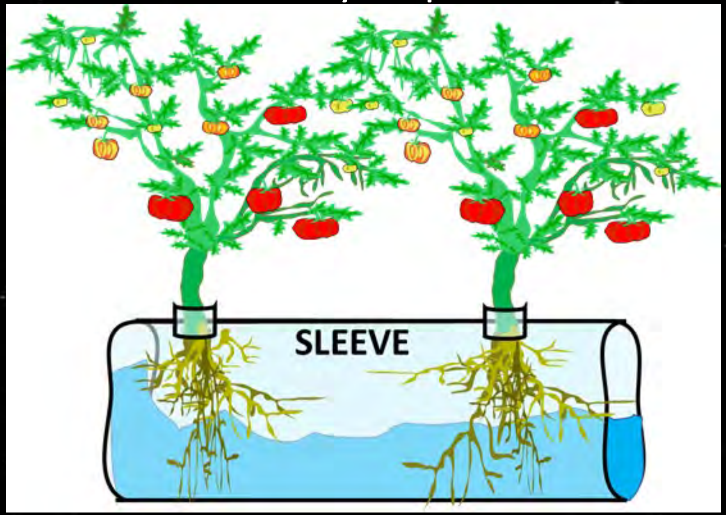
Shallow water



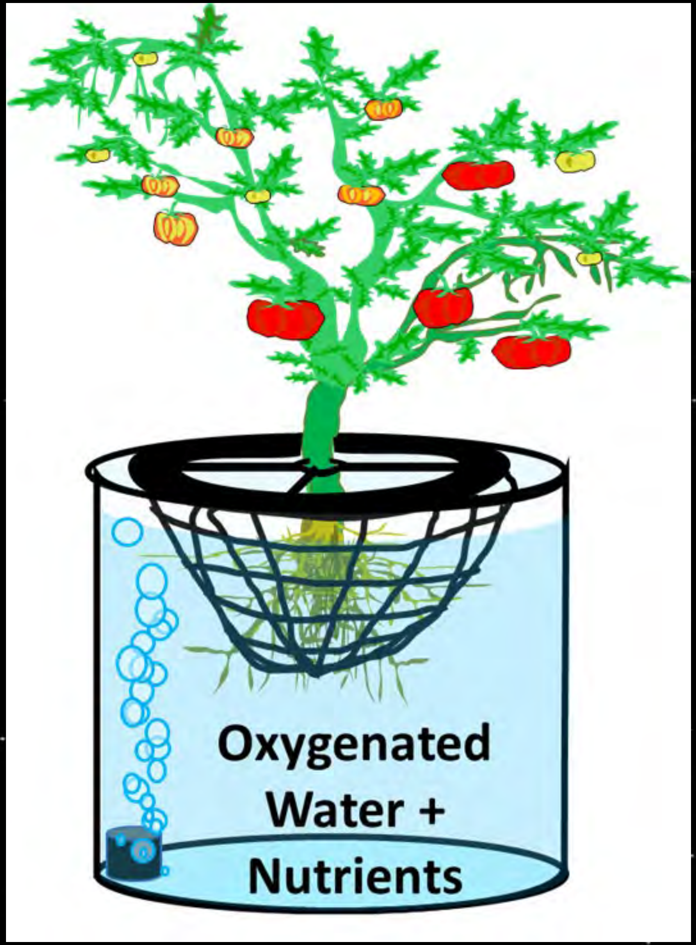
Substrate hydroponics



Sleeve hydroponics



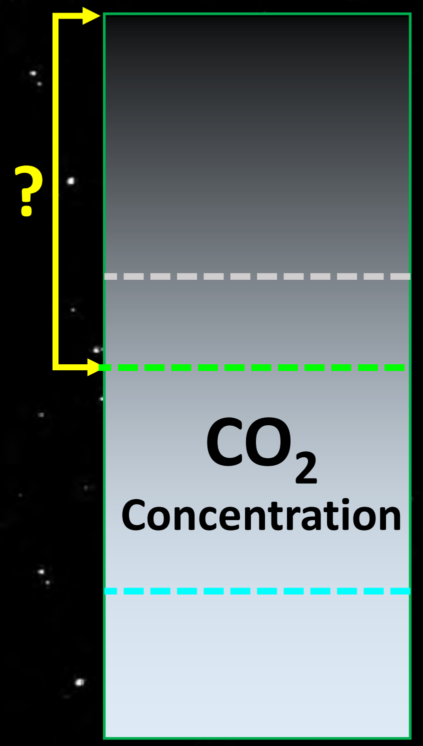
Bucket deep water hydroponics



Carbon Dioxide Enrichment

ppm=parts per million = 0.0001%

- Carbon dioxide enrichment helps growth for many crops, at times.
- Maybe to at least 1500 ppm?
- Research needed to see if:
  - CO_2 > 1000 ppm for what crops?
  - CO_2 increased with increased oxygen, nitrates, or water to roots?
  - Variations with air pressure, temp, light, and relative humidity?



5000 ppm (US OSHA maximum safe level for 8-hr human exposure)

1500 ppm (Early Carboniferous Period)

1000 ppm (Enriched Greenhouse 2022)

800 - 1000 ppm (very polluted city, bad day)

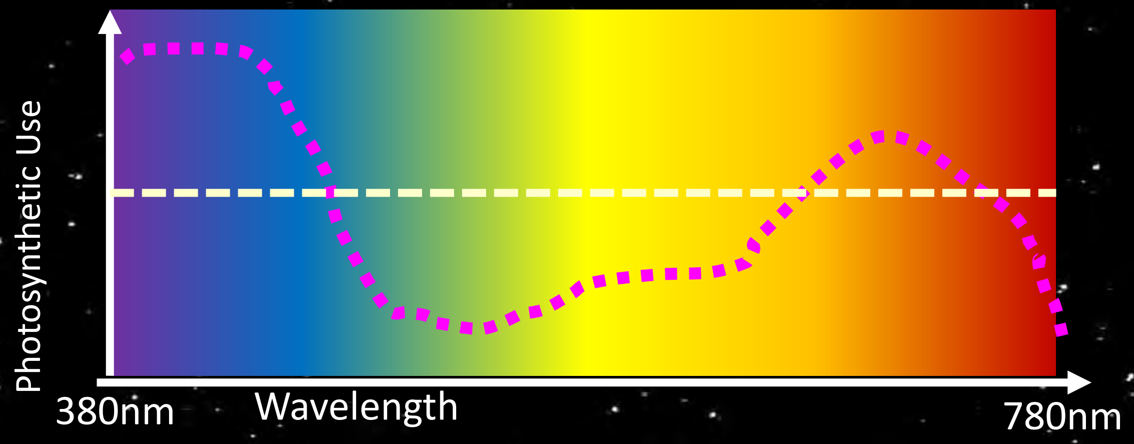
410 ppm (2021 Earth- Hawaii)

BIG Note: Air Circulation, Humidity Control, and Temperature control are critical in all indoor scenarios (i.e. in space too). Air circulation in greenhouse is at least 12-20 times per day for the whole aerial volume.

https://www.osha.gov/publications/hib19960605
https://geocraft.com/WVFossils/Carboniferous_climate.html
https://ucanr.edu/blogs/NurseryFlower/blogfiles/55782.pdf
https://hortscans.ces.ncsu.edu/uploads/c/a/carbon_d_52570d1851c70.pdf
https://extension.okstate.edu/fact-sheets/print-publications/hla/greenhouse-carbon-dioxide-supplementation-hla-6723.pdf

Lighting

- Earth: Sun provides 2GWh per acre during the wheat growing season
- Wheat plants to make 1 kg wheat get 2 MWh during the growing season.
  - This might be **way more** then the plant needs to produce optimally…tbd
- Lighting increases temperature at the leaf, but also for heat rejection in the air. LEDs are favored, as is tuning light spectra and periodicity to minimize heat.
- Currently there are various approaches to lighting, almost all LED based.
  - "Pink" grow lights versus "White-ish" Full Spectrum grow lights. Concerns and trades:
    - Temperature and heat rejection
    - Vegetative growth versus fruit growth
  - Timing? Intervals? Duration? Intensity?
    - Fruiting times may need lower light or periods



[Solar energy data: https://energy.mo.gov/resources/solar](https://energy.mo.gov/resources/solar)

Sensors and controls

- Sensors, Control, and Data using ML is key to maximizing production on Earth is all scenarios: Vertical, Greenhouse, Field.
  - Indoor operations use complex SCADA (Supervisory Control And Data Acquisition) systems. Need these in space for all crop production and plants, down to individual plant level.
- Sensor tech to maximum growth, detect disease, soil to hydroponic for crops, in use on Earth:
  - Visual/Camera/IR: Chlorophyll levels, disease detection, flowering, growth measurement
  - Chemical sensors: In root biome, hydroponic fluids: salinity/hardness/conductivity, oxygenation, pH, ammonia
  - Aerial Sensors: Humidity (Hygrometer), CO_2 and O_2, Thermometers
- Many sensors scattered inside growth areas and connected to processors with rulesets, and to troubleshooting/operations/response systems.
  - Many responses automatic based on use cases and rulesets
  - Humans notified and workflow systems ticketed
  - Logging systems store data for later analysis and root cause analysis

CONCLUSION

LOOK FOR MY SPACE FARM TEXTBOOK THIS FALL!!!!

- Many methods, techniques and technologies in use on Earth for high density field and greenhouse farming must be brought to space settlements!
- Data, and control and action using data, is the most critical technology for production today.
- Genetics and advanced biochemistry combined with soil-less technologies already in production can get food growth started now in gravity-based settlements.
- Many areas of work need to occur to optimize crop production of plant crops at various settlements: Free space, Lunar, Martian, etc.

References

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- https://energy.mo.gov/resources/solar
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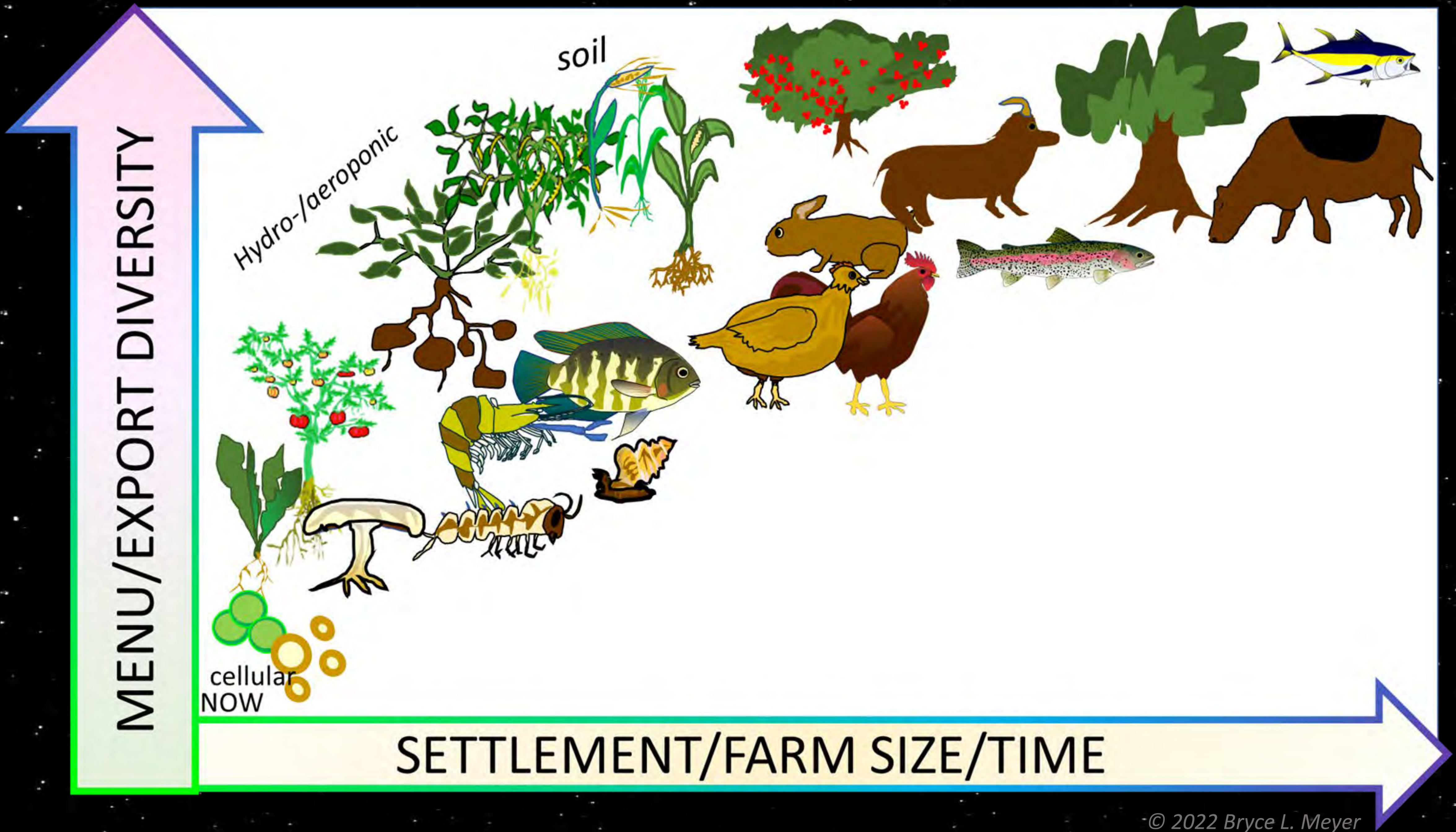
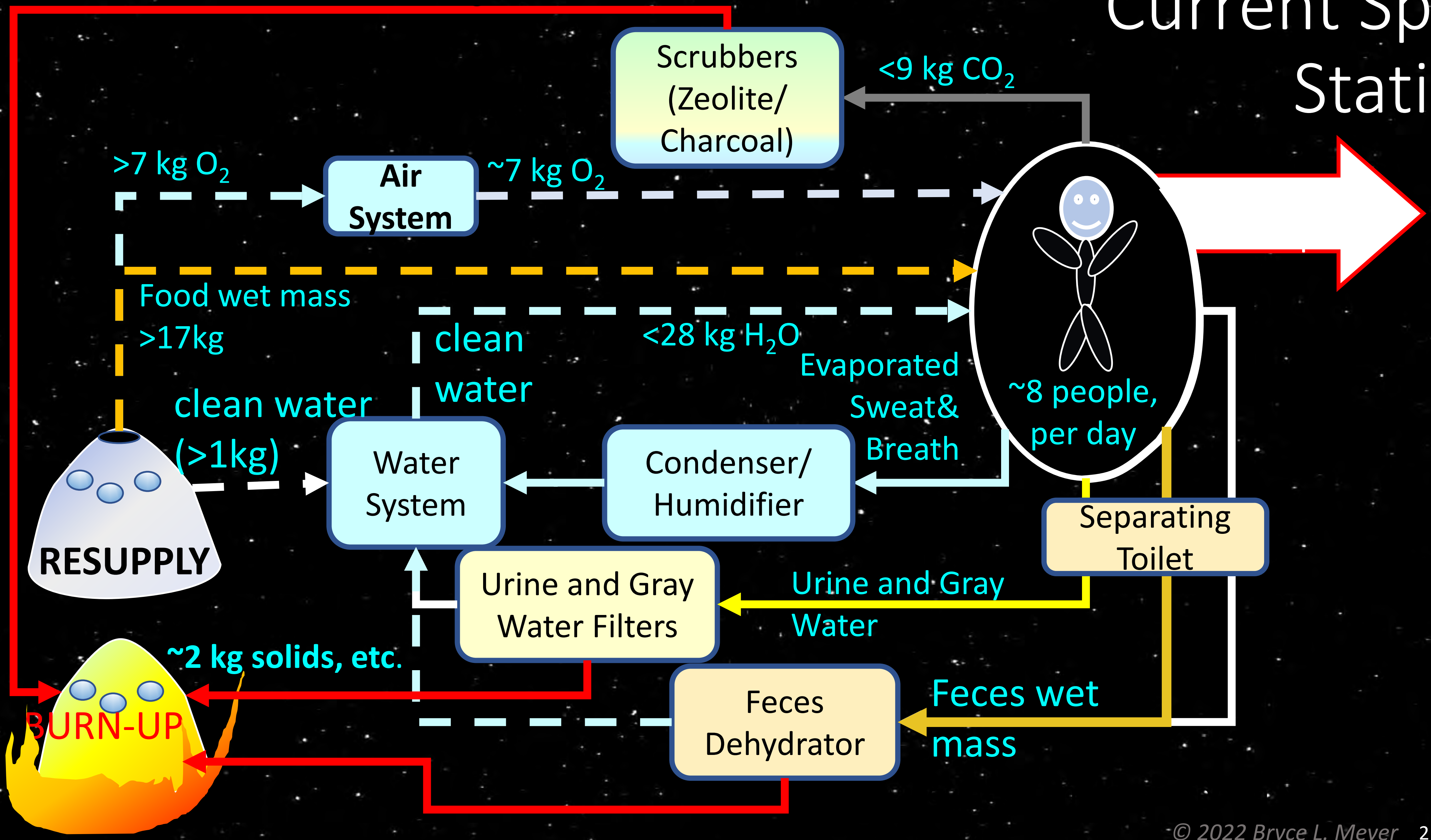
BACKUP

Why do I do space? Trillions of Happy Smiling Babies!



MENU/EXPORT DIVERSITY
soil
Hydro-/aeroponic
cellular
NOW
SETTLEMENT/FARM SIZE/TIME

Current Space Stations



How much **green** keeps me alive? (Super Rough)

Assume 0.8 kg O_2 **per day per person** (many very rough guesses follow):

- 0.8 kg O_2+ 0.3 kg C from food→1.1 kg CO_2
- Most Plants (Dry Mass) are around 40% Carbon.
- So, every day plants must add 0.3/40% = 0.75 kg of dry mass (roughly)
- How much plant/algae depends on the type, and how much water is in its living mass

Crop	Green Algae	Cyanobacteria	Lettuce	Tomato	Rice
% Water in wet mass (whole plant)	90% (100% edible)	90% (100% edible)	95% (99% edible)	85% (45% edible)	33% (50% edible)
Wet mass growth to get oxygen to breathe per day	7.5 kg	7.5 kg	15 kg	5 kg	1.2 kg
Kcal in growth/day in wet mass to get oxygen (need)	2,873 kcal	1,950 kcal	2,850 kcal	405 kcal	2,142 kcal* (at harvest)
Growth rate per day per kg live crop	8 kg/day	270 g/day	22 g/day	13 g/day	10 g/day
Starting wet mass (min) of living crop	2 kg	28 kg	682 kg	386 kg	121 kg

Schedule

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