Achieving Earth Independence: How Food Will be Grown?

Bryce L. Meyer
St. Louis Space Frontier

NSS ISDC 2019

Sunday, June 9, Concourse 1, 2:50 pm EDT

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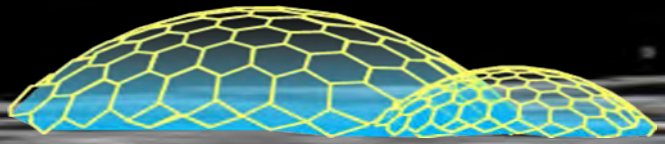
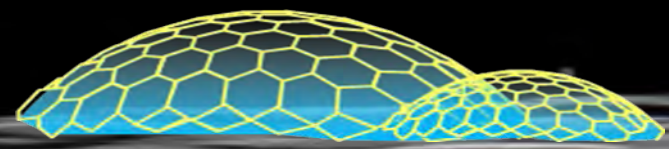


Outline

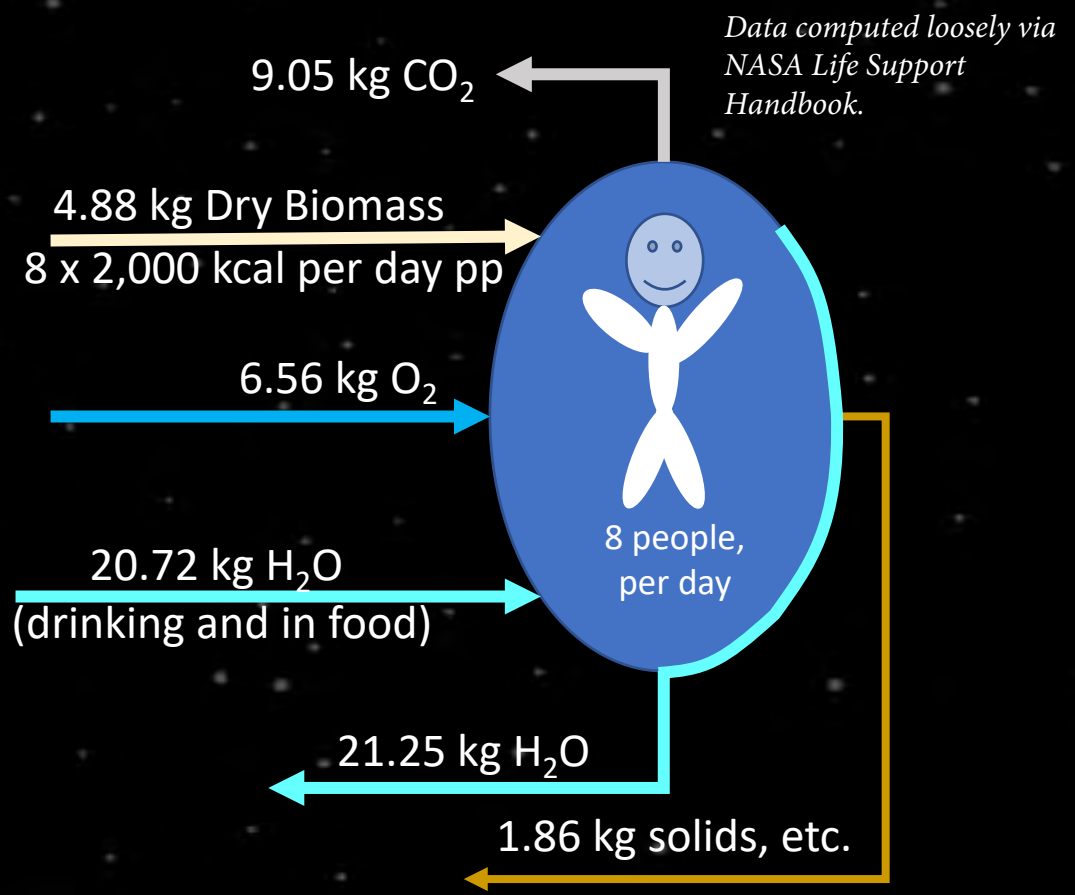
- How much for 8 (Earth Analogy)?
  - Mass Balance and Biochemistry
- What happens in space?
- Hydroponics and related technologies
- Algae and Photobioreactors
- Aquatic animals and insects
- Long term settlement planning



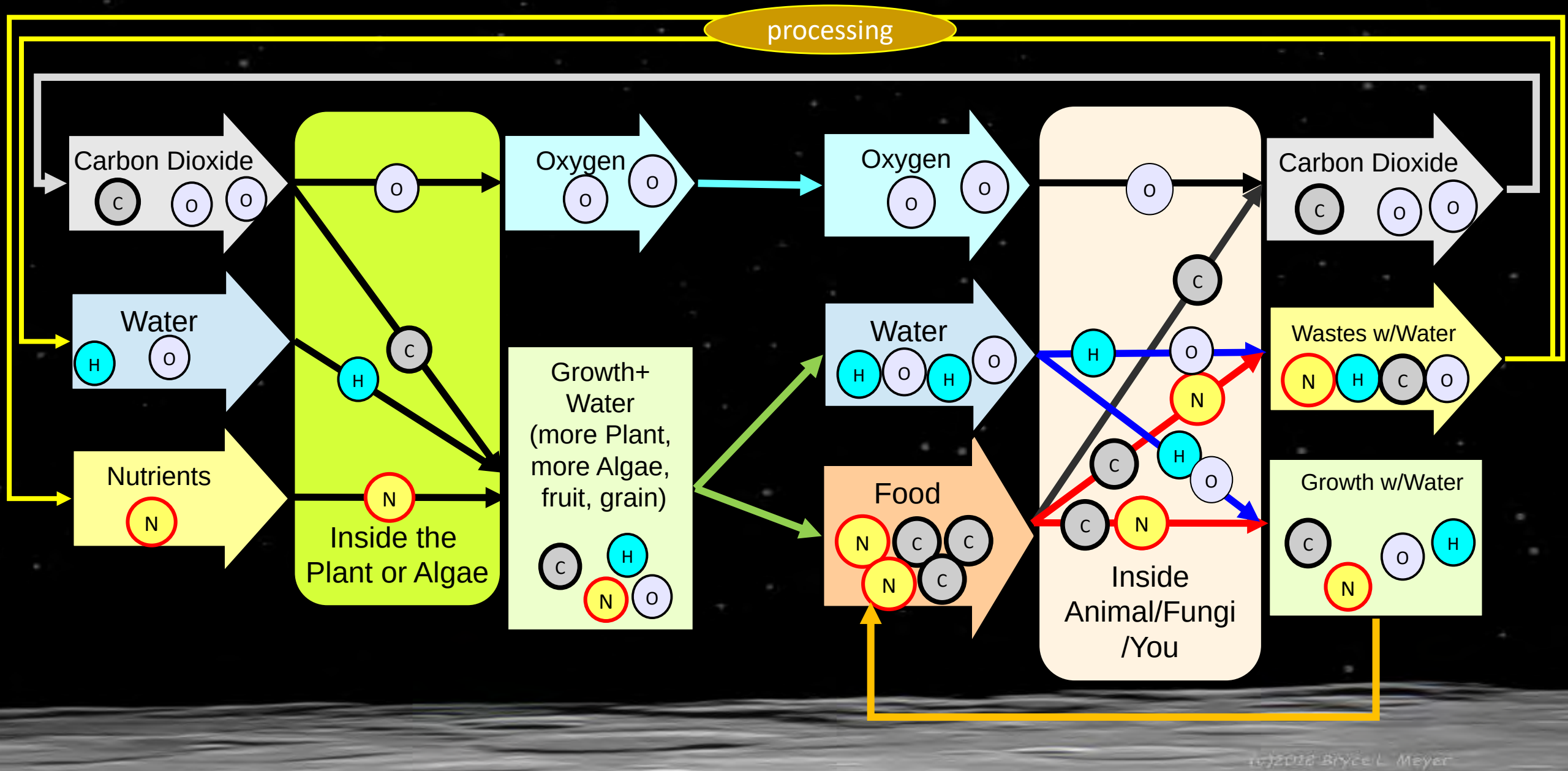
Basic Human Survival (as Modeled)

- People consume roughly per day (as per NASA, etc.):
  - 0.61 kg dry mass in food w/2,000 kcal (this can flex, as long as there is enough calories and the right balance of carbons, hydrogens, nitrogen)
  - 2.6 kg water in food and in drinking
  - 0.82 kg oxygen
- People hand off to space farms, recyclers, etc.
  - Dependent on diet inputs…
  - 2.7 kg water (in urine, feces, sweat, breath)
  - 0.23 kg dry mass in salts, solids (urine, feces, sweat, etc.)
  - 1.13 kg carbon dioxide

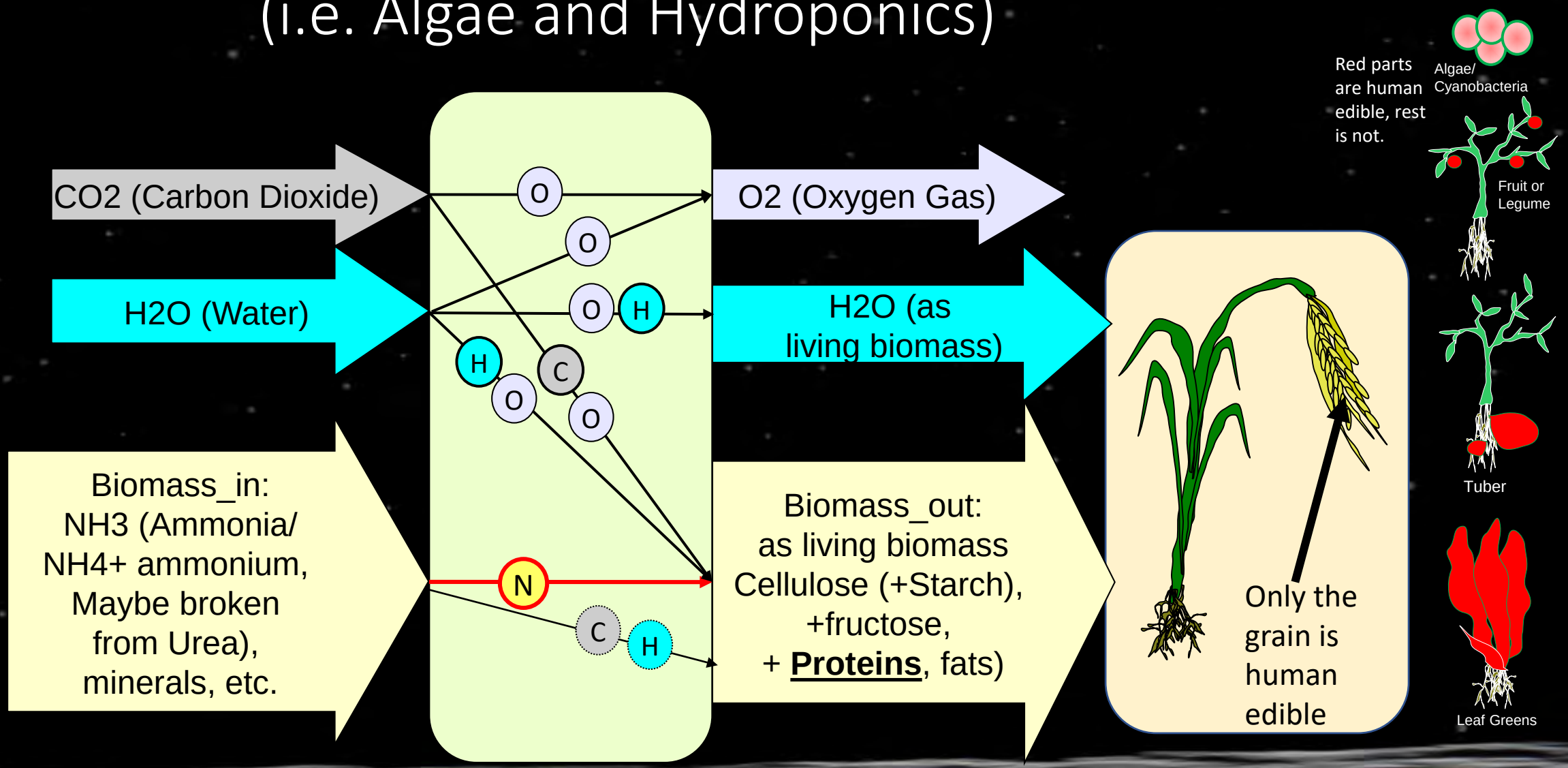
    Delta in mass between CO_2 and O_2 comes from food or around 0.5 kg in carbon
- FOOD DETERMINES MASS FLOW!



Simplified Biochemistry



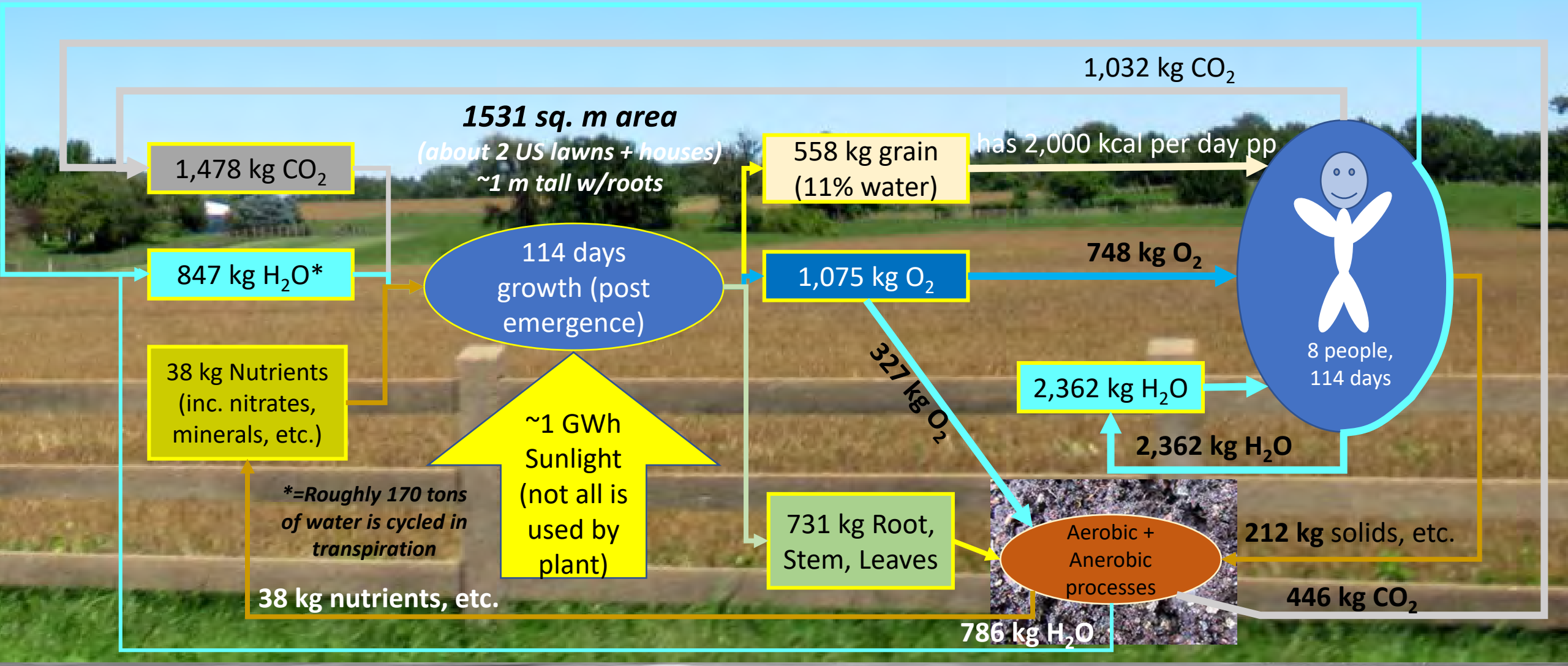
Mass Balance in Photosynthetic Organisms (i.e. Algae and Hydroponics)



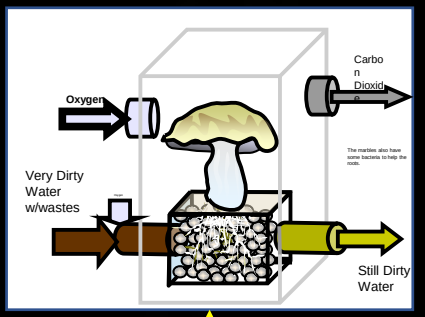
Food for 8: Earth Analogy

- On Earth, Farms are soil based and take in things we take for granted:
  - Assume all 8 settlers just eat wheat ("man cannot live on bread alone…" literally in this case) 114 day cycle:

Human values roughly from NASA Handbook, Wheat loosely from MO Dept of Ag.



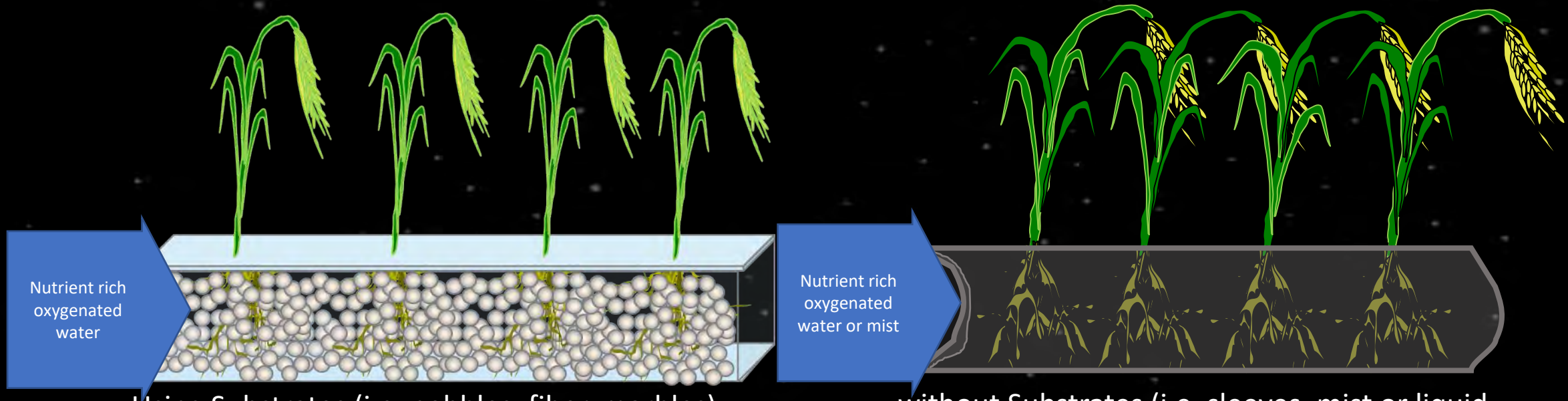
On to Space…



- Soil is replaced with hydroponics
  - Soil is great if you have the enclosed area/volume and time to make the soil biome.
  - Hydroponics/Aeroponics requires deep control of environment, but works quickly with little mass and volume.
- More then just wheat. Likely vegetables, soy, tubers, and grains
  - May include yeasts and other fungi. Yes mushrooms and grow hydroponically.
- Add bioreactors to replace soil reactions, and some food products
  - Combustion or other chemical processes can be used initially, at the cost of resupply or inefficiency.
- Add photobioreactors to add additional food source to balance nutrition, or to feed food animals
- Food animals when used likely fish, shrimp, or insects initially
- Reduce mass to moon or location, enclosed volume
- Use in-situ mass if available
- Reduce energy to minimal needs to gain efficiency

Note: **Grow out time for first crops is key..**
Algae and yeast can provide food in days,
Plants and fish/shrimp in months.
Initial supply must cover time to set up first crops (or robots can do it?)

Core Technologies:
Growing Vascular Plants w/o Soil



Using Substrates (i.e. pebbles, fiber, marbles):

- Costs:
  - Requires mass for substrate (in-situ or shipped)
  - Can clog if flow is not well managed
- Benefits:
  - Allows higher productivity using root fungi and bacteria

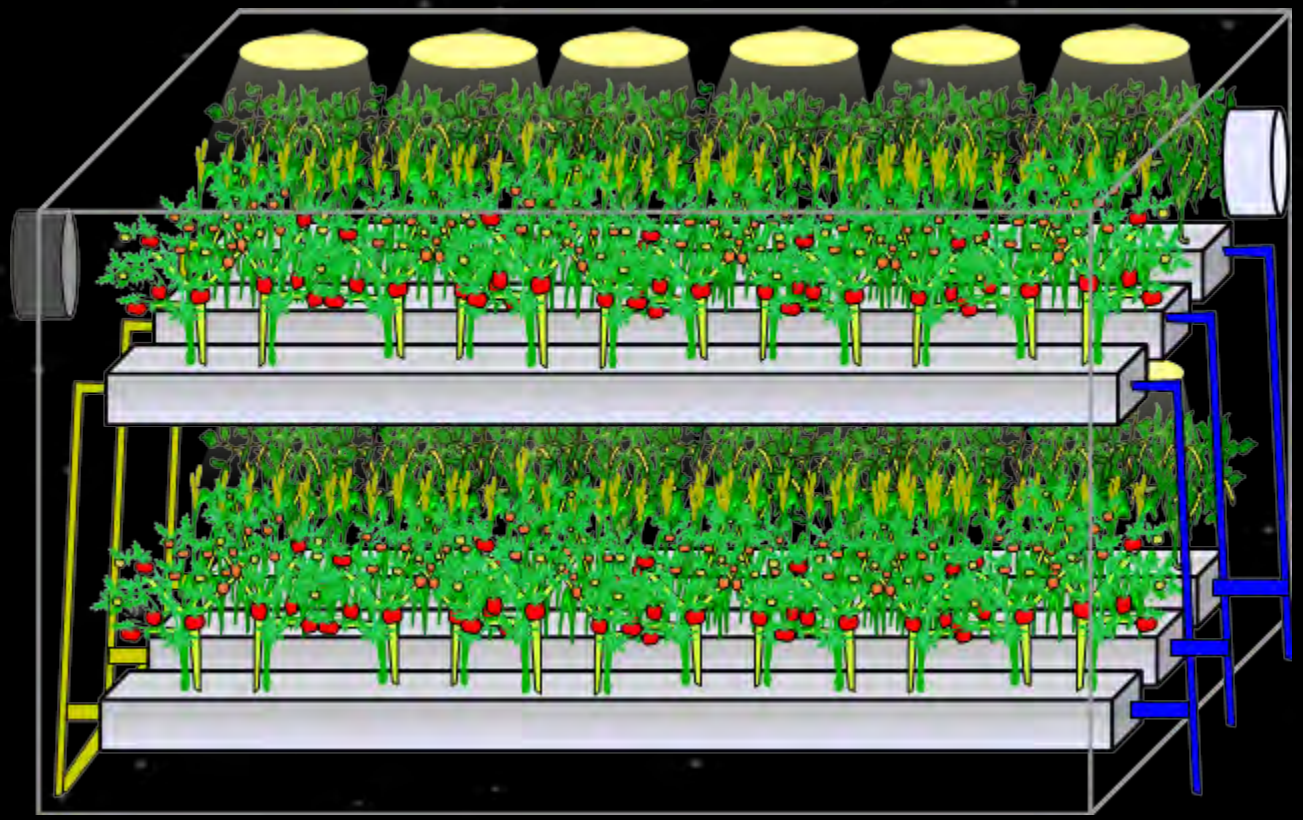
without Substrates (i.e. sleeves, mist or liquid systems):

- Costs:
  - Low bacteria and fungi growth in roots
- Benefits:
  - Very low initial mass and volume
  - Well controlled nutrient and root environment

Hydroponics: Implementation

- Hydroponic Stage uses:
  - Lighting above and around
  - pumps to push and pull liquids or mists through trays
  - oxygen injectors and nutrient mixers for root bed (or complex pump cycle to oxygenate roots)
  - Fans to move air around plants
  - Condensers to collect transpired water
  - Sensor arrays to monitor roots, plants, with complex control systems, filters to protect pumps.
  - Pumps/Fans to manage heat level and rejection
- Human Labor: Pollination, pruning, watching sensor arrays and control systems, filter changes, etc.
- Most of the structure can be built using in-situ materials
- Initial load: seeds, sensor/control systems, pumps, lights.

To feed 8: ~700 m area x 3m tall +/- (about an average American house + lawn, assuming diverse crops)



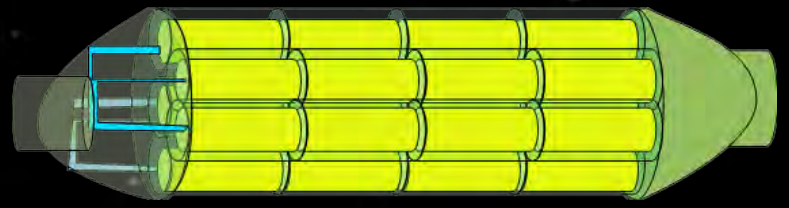
In Habitat Growth

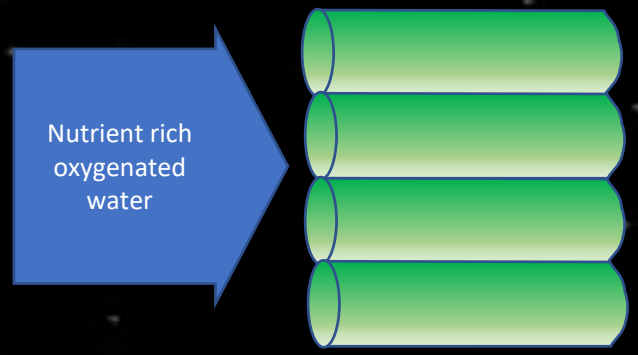
- Corners, tabletops, hallways, walls inside habitats can all be added to food production and oxygen recycling, especially for spices, herbs, and dwarf fruit and coffee plants.
- Can use grey water from showers, sinks, food prep.

Spice	Time to First Harvest (wiki)
Basil	75 days
Cilantro	30 days
Dill	90 days
Fennel	100 days
Mustard	95 days
Chives	60 days
Marigold (Candula)	70 days
Mint	90 days
Tarragon	60 days
Oregano	120 days
Cumin	120 days
Ginger	200 days
Serrano Peppers*	120 days
Paprika*	150 days
Saffron	180 days
Chili Peppers*	120 days
Coriander	100 days
Garlic	180 days
Turmeric	300 days
Thyme	1 year
Rosemary	1 year
Hops	2-3 Years
Coffee**	2-3 Years
Tea**	2-3 Years
* = Same species as bell peppers	
** = large enough to require space and possibly a hydroponic stage, good for export!	

Core Technologies: Photobioreactors

- High Density Machinery to grow cyanobacteria, algae, or edible water plants (all called ‘algae’ for simplicity here).
- Can be open format or use membrane or mesh confined algae
- Shape optimizes exposure of algae to CO2 and nutrient infused solution and light
- Like sleeves for hydroponics, a low weight reactor shape is a drape or sheet reactor, with free flowing algae, with external lighting
- Lights can be immersed or external
- Products are whole algae cells (90% water), cleaner water, and oxygen.
- Pros: Much more compact than hydroponics, especially for early settlements, very fast to first harvest (a few days after switch on).
- Cons: Requires whole machines, lights, and control systems. Algae can be very fragile.
- Can be used to make human food, or food for animals (esp. aquatic organisms, insects)



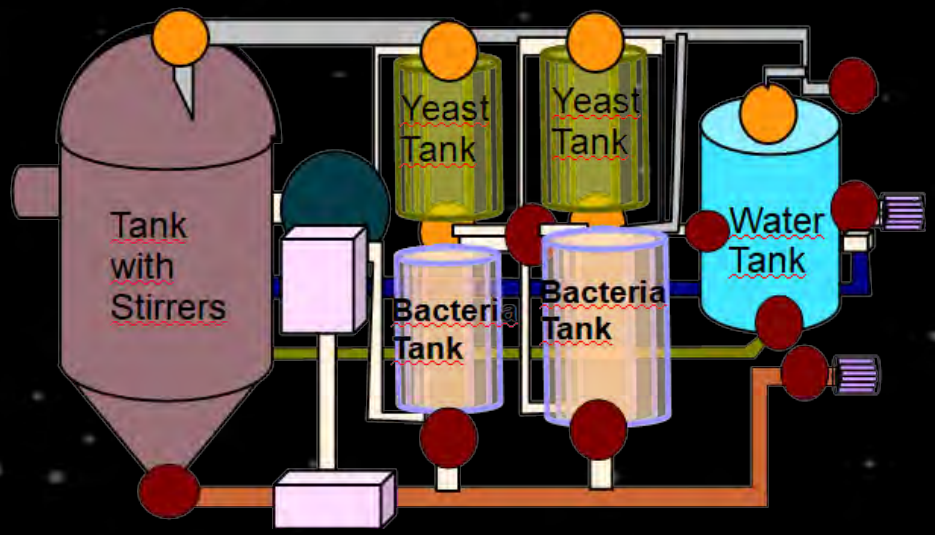


Note : for free flowing algae, pumps must not use impellers (i.e. be fluidic pumps or slow stirrers)

Core Technologies: Bioreactors and Carbon Harvesters

- Most biomass produced from plants is inedible matter (cellulose, etc.)
- Humans pass through most of the mass consumed.
- Carbon, Hydrogen, Nitrogen are locked in wastes.
  - Need CO_2 and H_2O to close the mass cycle.
- Earth: bacteria and fungi do most of the breakdown, followed by wildfire.
- So to get Carbon Dioxide:
  - Fermentation: Membrane based and open tank. Duplicates cow stomachs and soil.
  - Combustion: Oxygen or anoxic controlled burn to minimize undesirable products
  - Other Chemical Cycles: direct enzyme digestion/oxidation, and others.
- Of course, on Mars, CO_2 is plentiful, but on the Moon or especially in free-space, carbon is not as plentiful and must be resupplied or recycled.

Can be a simple vat as used for beer or wine, or complex like the design below:

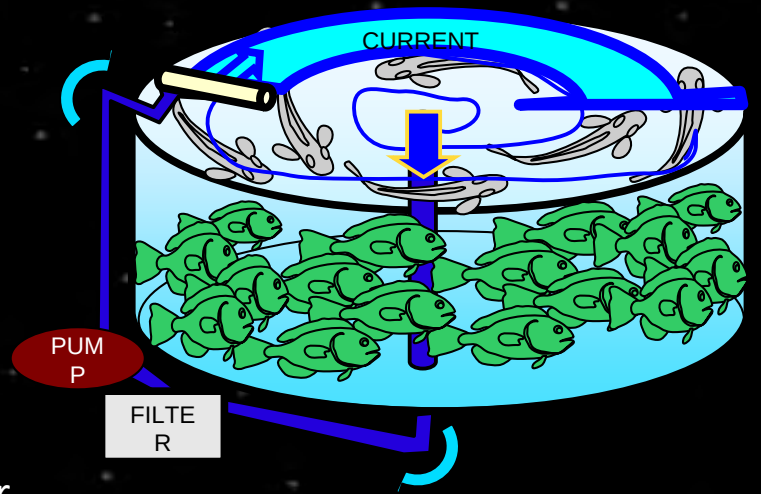


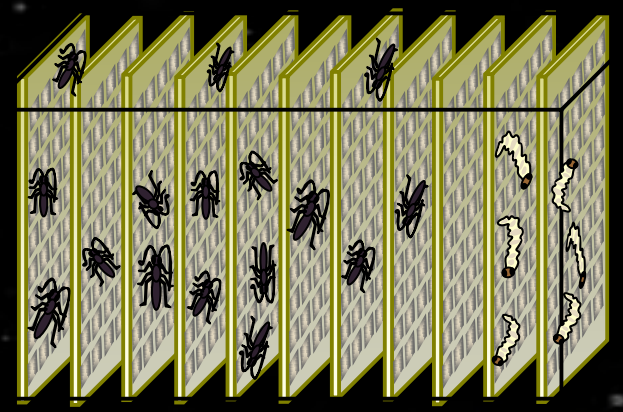
Can also produce high protein foods (i.e. yeast, lees) with even a simple vat fermenter.

Core Technologies: Animals

- Even if uneaten (i.e. pets):
  - Partially recycle nutrients and plant/food wastes, output can be used for Hydroponics
  - Add CO2 to cycle for plants
- If Eaten:
  - High density protein source (i.e. high protein per kcal)
  - Dietary variety
- Core Tech for small settlements:
  - Aquaculture: High density tilapia, shrimp
    - Requires water, most of stage can be built in-situ
    - Round tanks are best for small populations, raceways for larger settlements. Raceways can be set up with hydroponic beds.
    - Ship frozen gametes, Extra area for breeders
    - Species: Must eat algae and plant wastes, freshwater species first.
      - i.e. tilapia, silver carp, prawns, etc.
  - Insect-culture: Mealworms, crickets
    - Very Small initial mass, though requires gas processing
      - Fans and filters, due to high ammonia/methane

Note: 50kg of fish/ shrimp/ mollusk per cubic meter of water (max.), twice that for breeders or aggressive species





What can be grown when?

Settlement Size	Chemical Processors	Photobioreactors	Anerobic/ Aerobic Bioreactors	Hydroponic (substrate-less)	Hydroponic (w/substrates)	Soil Farm	Insect Farm	Aquatic Animal	Land Animal
8	x	x		x			x	(pets/grow-out only)	
20	x	x	x	x	x		x	x	(pets only)
50		x	x	x	x		x	x	(pets only)
100		x	x	x	x		x	x	(pets only)
500		x	x	x	x		x	x	Rodents, maybe chickens
1,000		x	x	x	x	x	x	x	Rodents, Goats, Chickens
10,000		x	x	x	x	x	x	x	Large Animals

Thank You for Coming!

And remember:
Why do we settle space?

Trillions of Happy, Smiling Babies!

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