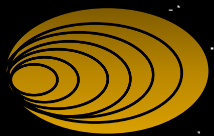







Bio- Sustainability: Role of Aquaculture in Space

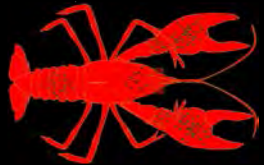
Bryce L. Meyer
St. Louis Space Frontier

NSS ISDC 2019

Friday, June 7: North 2: 11:20 am EDT








Outline

- Closing the Mass Cycle
- How does aquaculture work?
- Why Aquaculture in Space?
- Species?
- Systems and machines

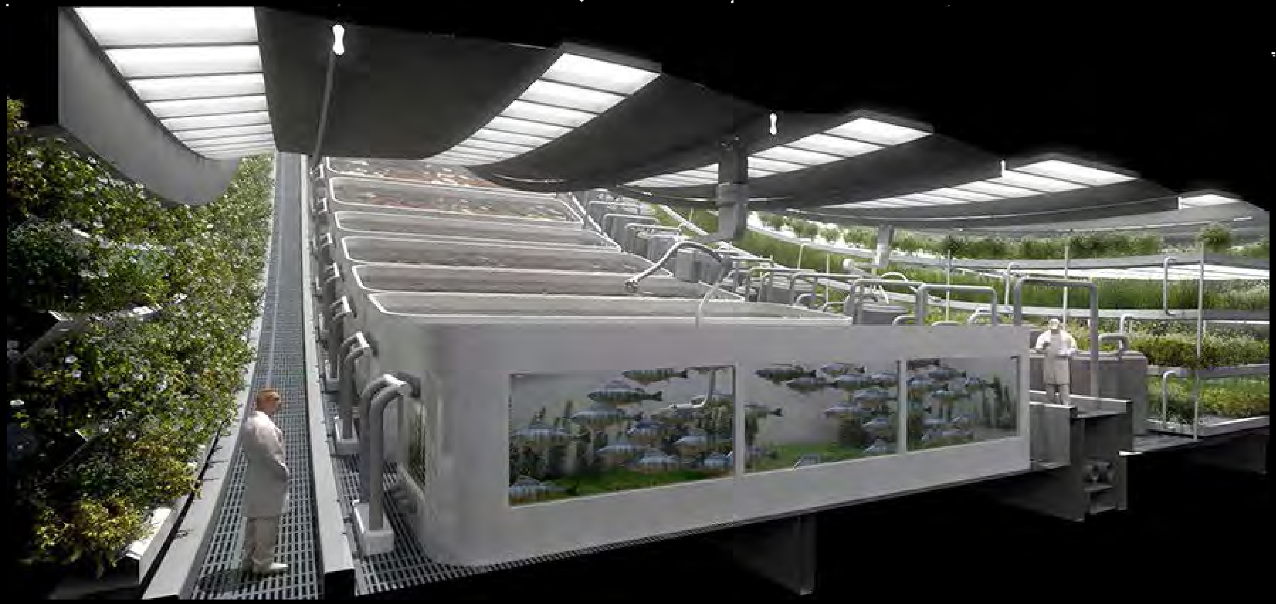
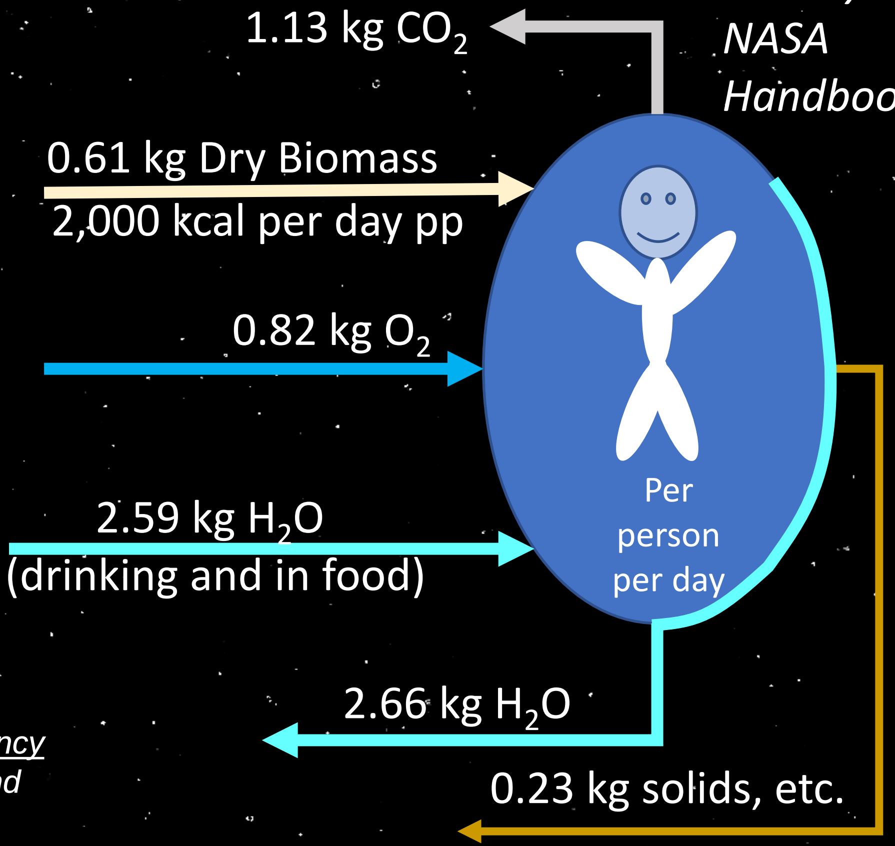


Image: Bryan Versteeg, spacehabs.com

Human Settlement (Habitat)

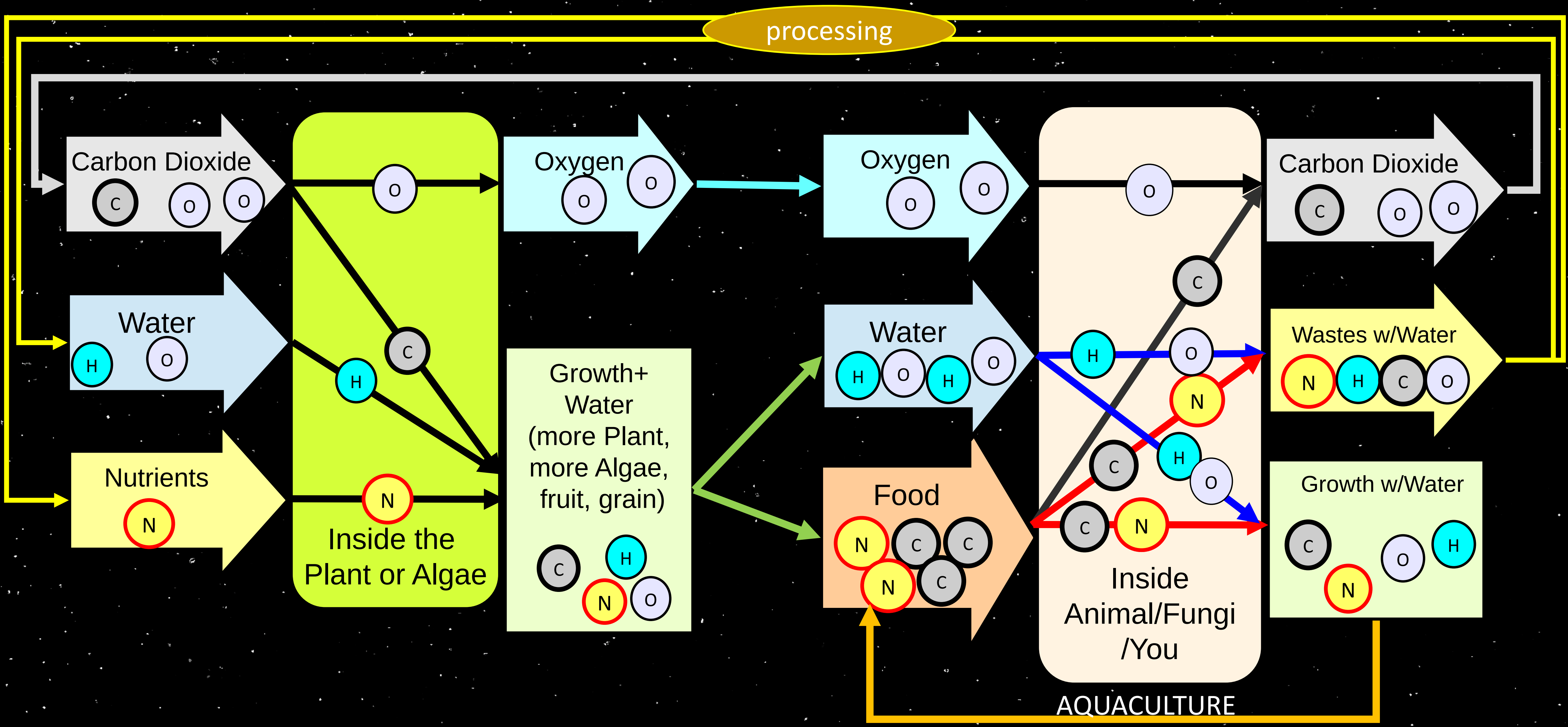
- Dietary Diversity is Key to Psychological Health
- Space Farms are the core element in a self-sustaining (mass-wise) long term settlement.
  - Resupply is expensive
  - In-situ if available replaces inefficiencies.
- Space Farm takes the outputs of the Human Habitat and outputs food, clean water, and oxygen.

Loosely via NASA Handbook

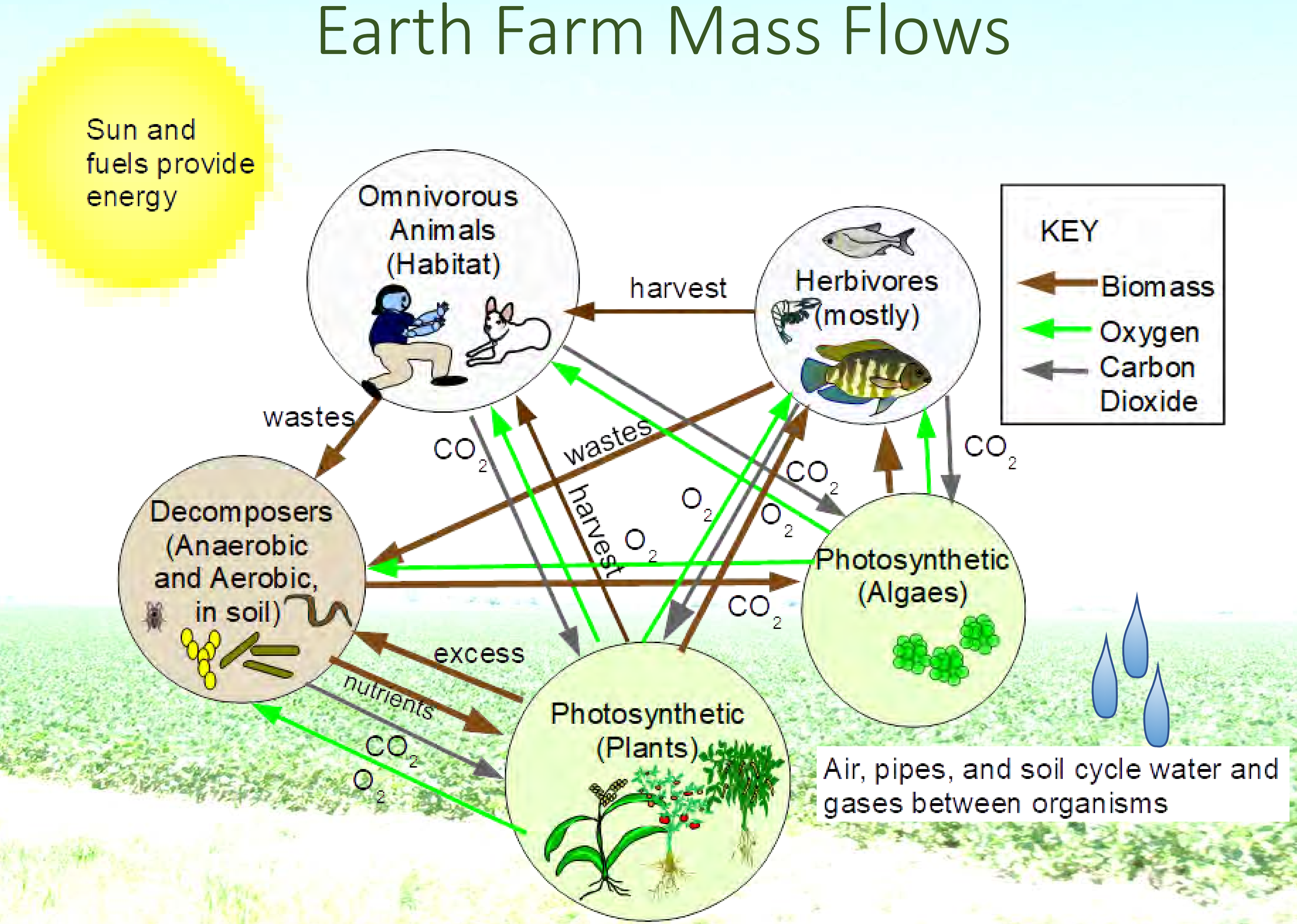


[NSS Space Setttlement MILESTONE 9: Technology for Adequate Self-Sufficiency]
People leaving Earth with the technology and tools needed to settle, survive and prosper without needing constant resupply of survival essentials from Earth.

Simplified Biochemistry



Earth Farm Mass Flows



Mass in and Mass Out

- Roughly the same for many fish species….
- Once the growth (mass accumulated/day/kg live animal) curve slopes off, time for harvest
- For fresh food: Continuous harvest means keeping a stream of growth classes and breeders
- Animals accumulate mass by adding dry biomass mass + water, cubic based on volume (mass)

Due to the need to overfeed, excess food ends up as solid wastes

Food: Wet Mass: >10g (assume algae, 90% water)

Oxygen (in water): 1.5g/day

Water ingested: >4.7g/day

1kg of living fish mass (Multiple fish)

Retained in growth: wet mass: 6g/day avg. (78% water)

Carbon Dioxide (in water): 2g/day

Wastes: Wet Mass: >8.2g (>0.8g dry mass)

Freshwater has ~0.8% salts and minerals
(i.e. 8 grams per 1 kg water)
Saltwater has 2.8-3.5% salts and minerals per 1 kg

General rule for raceways: **50 kg fish per cubic meter** of water at harvest (REF 2) . Some fish can be denser (African catfish up to 5x as dense [REF 18])…a research area?

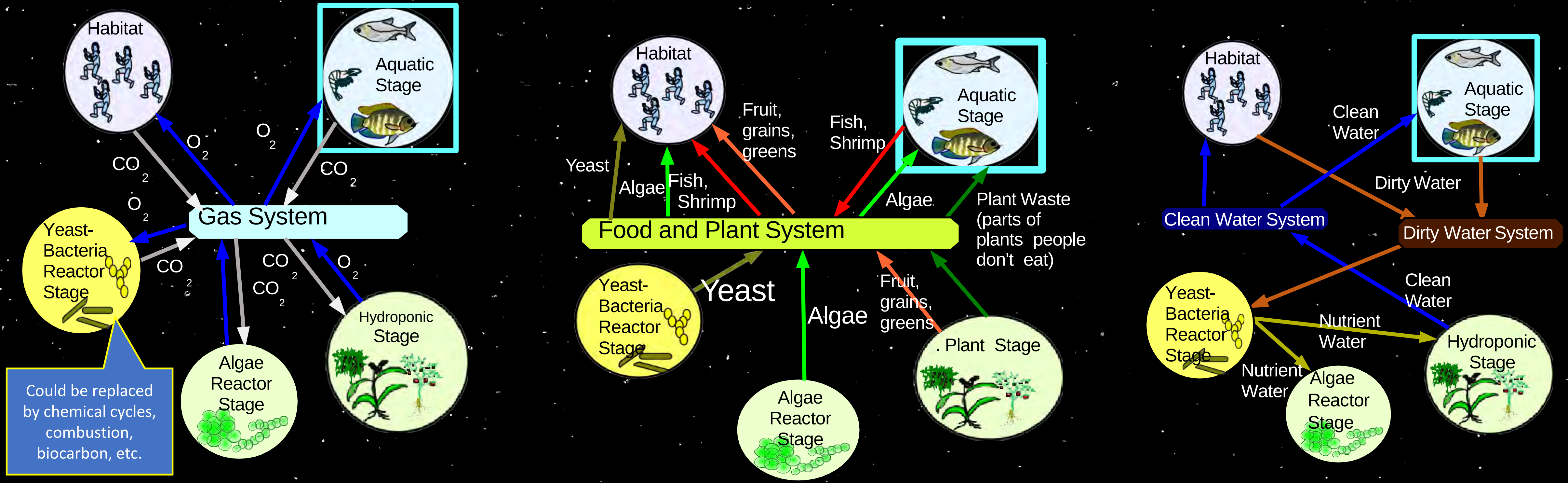
Energy: < 1kW/day/live kg

Space Farm Mass Flows

In Space, all mass should be conserved and minimized.

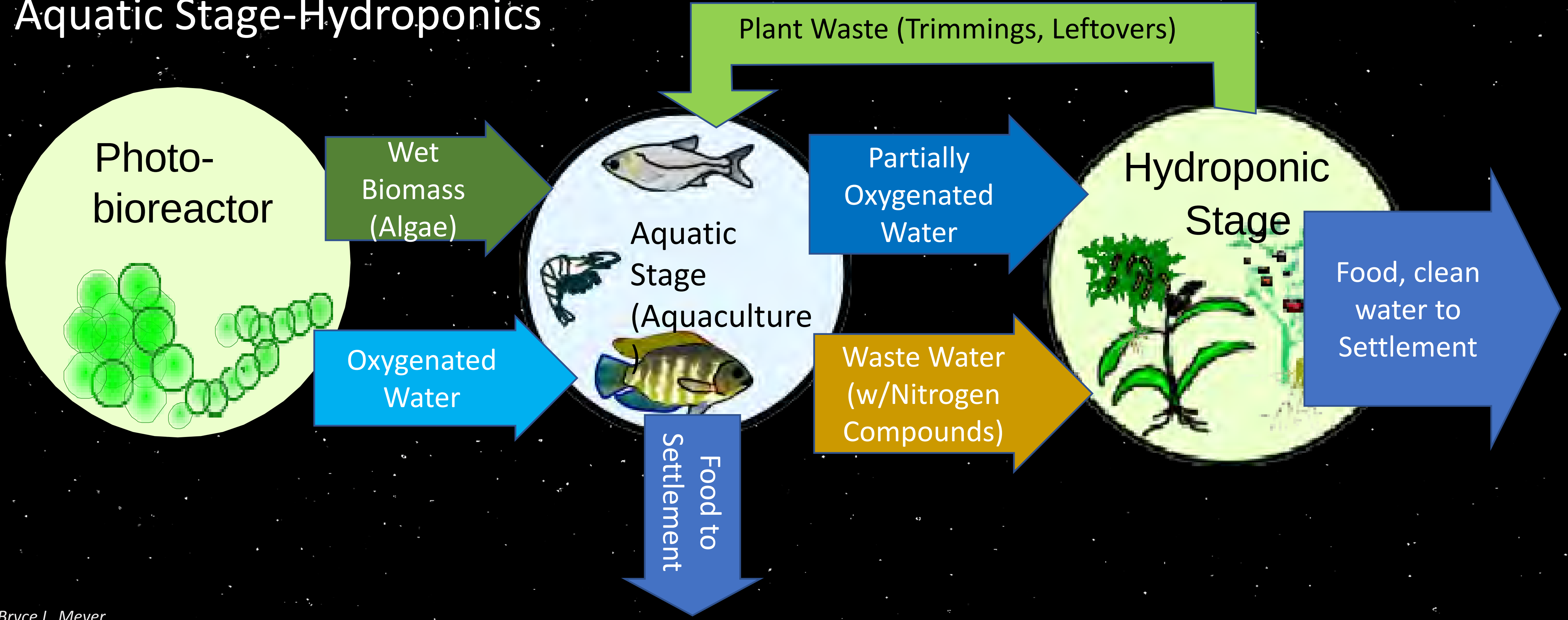
Space Farm + Habitat = Closed Mass Cycle Ecology

Humans: Food+ Oxygen + Water → Water + Wastes (w/Cellulose)+CO_2
Animals: (Plant Wastes + Algae + other Wastes) +Oxygen → Water + CO_2 + Wastes (w/Cellulose)
Plants and Algae: Energy + CO_2 + H_2O + Nutrients → Cellulose and Foods
Human + Other Animal Wastes + Plant Wastes +Energy + Water + O_2 → Nutrients + CO_2 + Water



Virtuous Flow: Photobioreactors + Hydroponics + Aquatics

Near Mature Space Farm: Core Mass flow between Photobioreactor-Aquatic Stage-Hydroponics



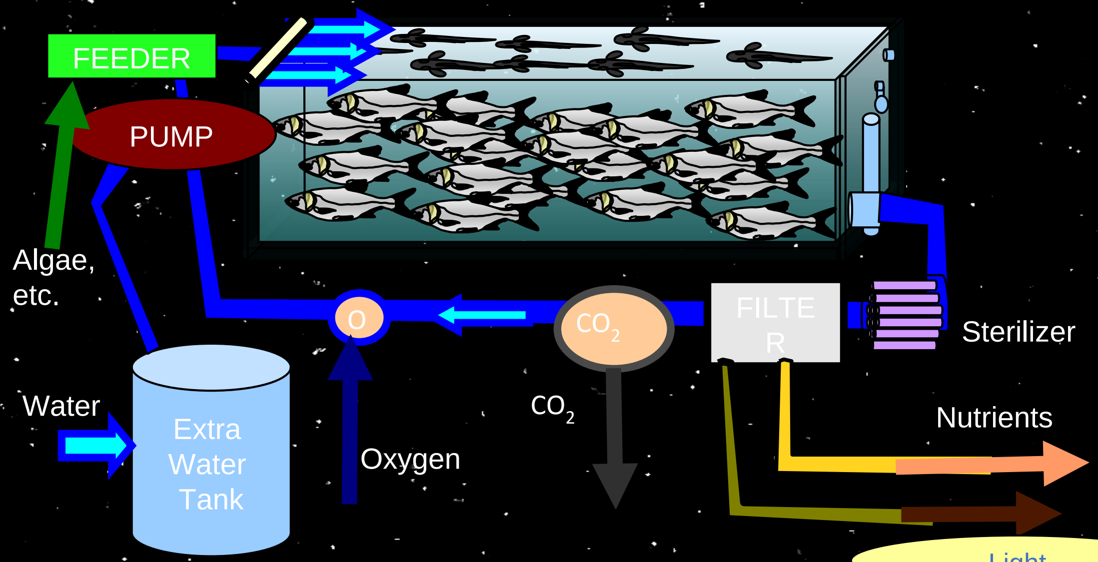
Aquaculture 101

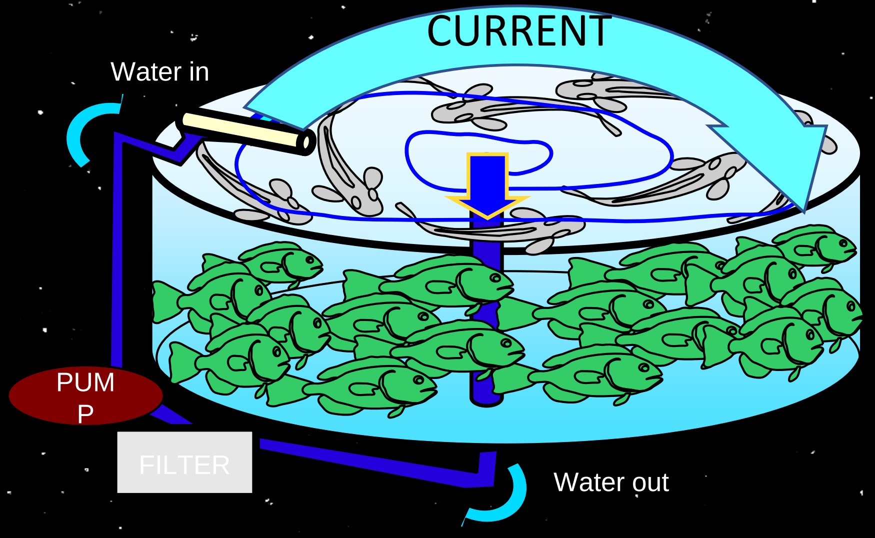
- Aquaculture is the creation of an artificial environment to maximize the growth and production of aquatic organisms for food.
  - Invertebrates
  - Fish
  - Complex Plants: Kelp, Elodia, etc.
- Two major types: Monoculture and Polyculture
  - Monoculture: One Species in each tank
  - Polyculture: Multiple Species in Each Tank, including snails, algae, etc.
- Two major Architectures: Raceway and Round Tank
  - Zero-g: Tube and Sphere…
- Unlike plants, for many fish and shrimp, the entire organism is edible, with some processing.
- Simple cycle: Fish tank water to Hydroponic roots to algae tank to fish

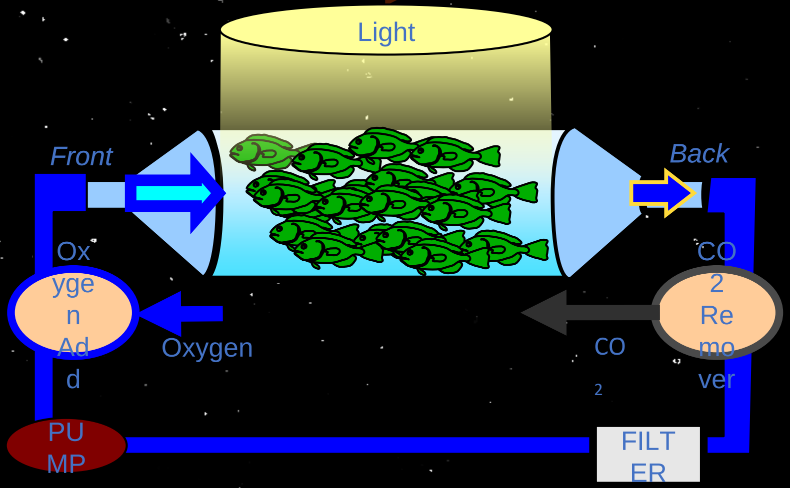
What is the role of Aquaculture in Space Settlements and Exploration?

- Animals add protein and dietary (menu) diversity
- Aquatic Animals balance the CO2-O2-Water and Nutrient cycles to compliment plants and algae components of a space farm.
  - People do not exhale enough CO2 to feed themselves.
  - Waste water can be directly circulated through hydronic beds or algae tanks to improve photosynthetic production (i.e. aquaponics)
  - Aquatic animals partially break down plant wastes
    - Fish and shrimp mechanically digest material, leaving wastes that are easily digested by bacteria in vats or bioreactors.
    - With more processing animal or human wastes can be fed to some organisms, especially if wastes are fermented and oxygenated first.
- With aquaculture the mass cycle becomes more efficient.

Aquaculture Technologies





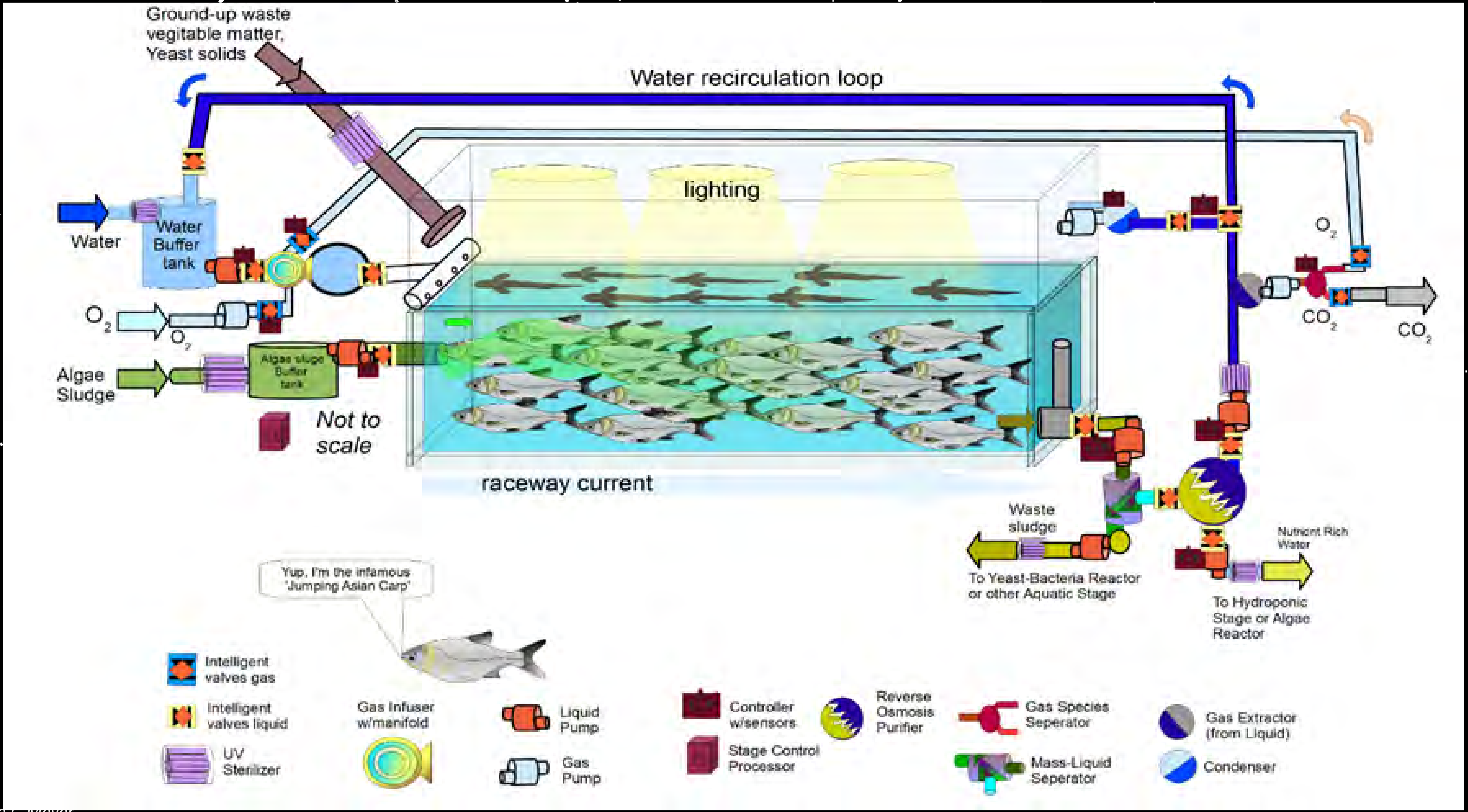


Note: Some species will require dividers to prevent aggression

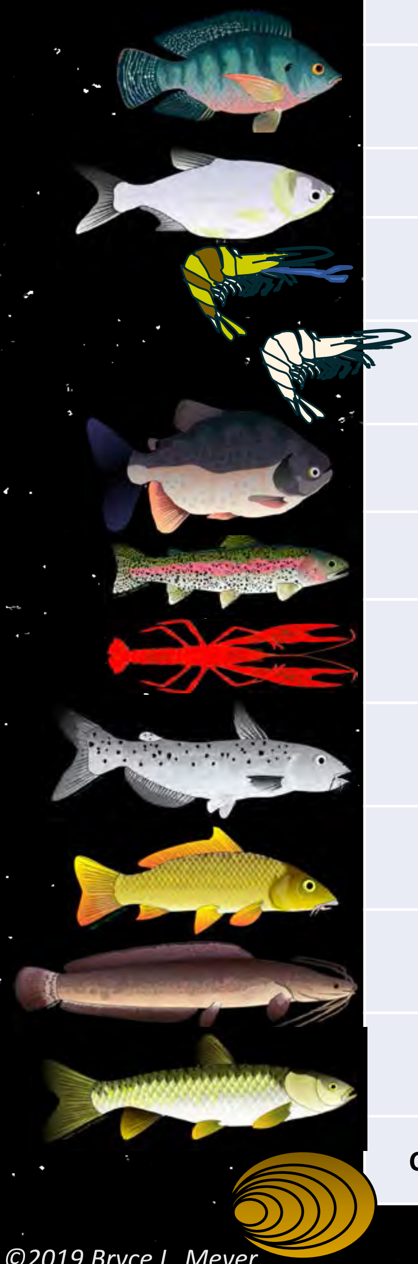
Machinery for Tanks

- Lights to orient animals
- Pumps to recirculate water
- Separators to catch wastes (combined with Reverse osmosis filters), Filters to protect pumps
- Gas separators to extract excess CO_2 in large stages
- Oxygen injector columns with air pumps
- Thermal control (heat rejection) coils, fins, pumps
- Fans above tanks to circulate air, with dehumidifiers to prevent mold in tank area.
- Feeders to automatically feed animals
- UV sterilizers to prevent contamination
- Sensor arrays and control system to optimize temperature and chemistry of water, and monitor animal health.

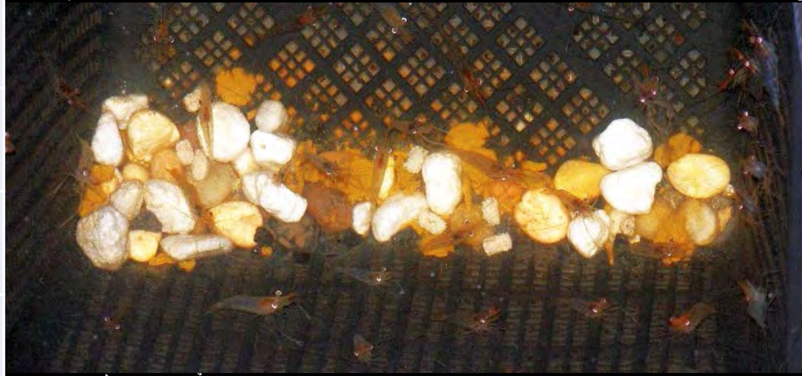
Machinery for Tanks (Continued)



Candidate Species (Rough Data)



Species	Days to Harvest	mass at harvest (kg/animal) ideal	Days to Breeding	Feed
Tilapia	150	0.300	365	algae, plant wastes, animal wastes
Silver Carp	365	1	365	algae, plant wastes
Freshwater Prawns	180	0.124	365	algae, plant wastes, animal wastes
White Shrimp	120	0.02	365	algae, plant wastes, animal wastes
Pacu	365	1.2	365	plant wastes, animal wastes
Rainbow Trout	252	0.5	1460	animal products and soy feeds
Red Claw Crayfish	240	0.02	365	algae, plant wastes, animal wastes
Channel Catfish	730	0.6	730	algae, plant wastes, animal products, soy
Common Carp	1095	3	1460	algae, plant wastes, animal products, soy
African Catfish	300	1	365	algae, plant wastes, animal products, soy
Grass Carp	550	1.5	1460	algae, plant wastes, animal products, soy
Clam (R u d i t a p e s)	1095	0.015	1095	algae, dissolved wastes



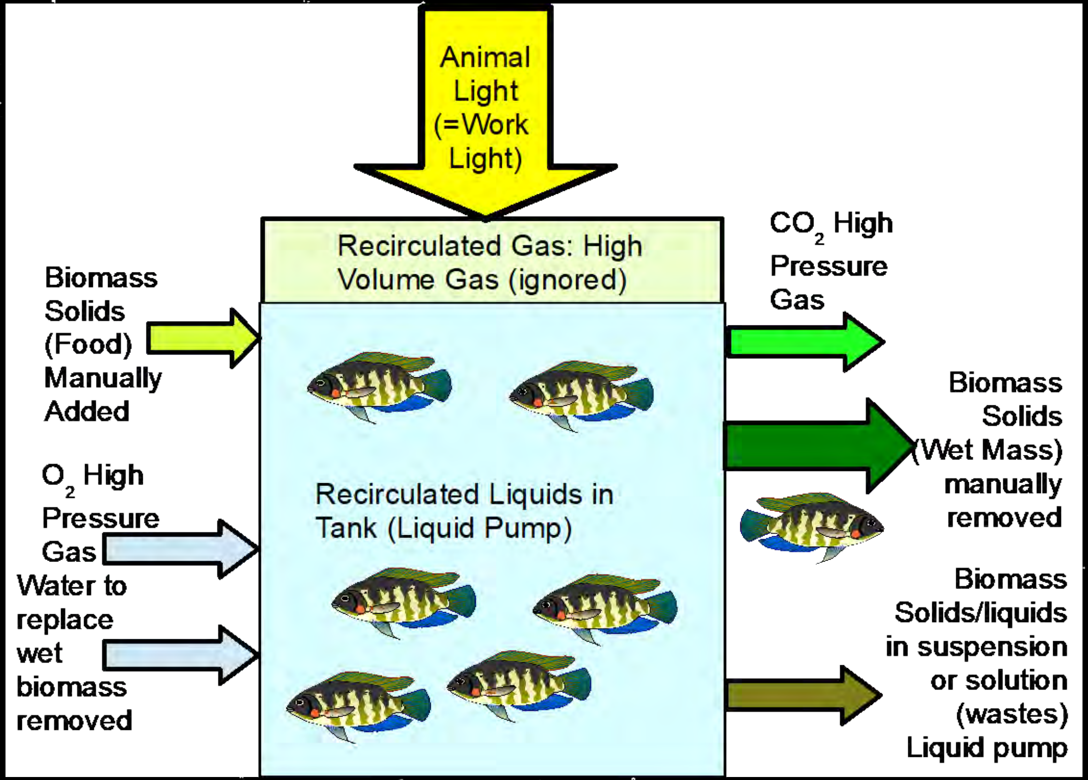
Species Selection favors fast growing, schooling species, that can thrive on algae and plant wastes

Polyculture

- Even a single species tank should be seeded with algae and bacteria to balance the biochemistry of the tank
    - Roughened side walls, gravel bottom
    - Snails and isopods/amphipods clean tanks
    - Daphnia clean water and provide extra food to animals
- Adding a section with Elodia or similar can-pre-clean water before recirculation and reduce filter cleaning
- Two or more food crops can increase productivity:
    - Plants and fish
    - Multiple fish: ex: Silver Carp, Common Carp, Grass Carp
    - Fish and large invertebrates e.g. tilapia and clams, silver carp and tilapia, etc.

Energy Consumption

- Pumps to recirculate water and power separators is the largest energy requirement (~1kW/day/living kg)
  - Assumes 25kg fish or shrimp per cubic meter water, or half level at harvest…worst case.
- Heat Rejection, Lighting very much less consuming then pumps but essential.

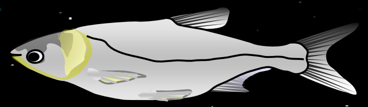
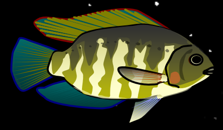


Sizing and Initial Mass

- Initial Mass:
  - Plan for initial crop size based on complexity of overall space farm.
    - Worst case estimates: about 80kg of water, 0.17 m3 per settler for a 2kg living fish (harvest of 500g every 180 days).
    - For a 100 person settlement, a mature three species aquaculture portion (with full balancing hydroponic, bioreactor stages) (silver carp, tilapia, shrimp) was estimated at (WORST CASE) ~9.44 cubic meters volume, ~4.58 mt water per settler:
    - Much smaller footprints however would work.

Species	Stage Type	Volume (m3)	Mass (mt)	Water Mass (mt)	Footprint* hectares
Shrimp	Aquatic	733	524.06	357.94	0.02
Silver Carp	Aquatic	128	91.4	60.01	0
Tilapia	Aquatic	83	59.6	40	0
TOTAL		944	675.06	457.95	0.02
Per settler		9.44	6.75	4.58	0

CONCLUSION

- Aquaculture adds a key stage to a complete space farm
  - Provides dietary diversity and helps close the mass loop, even if not eaten
- Core technologies include raceways and tanks
- Some species are better then others:
  - Quick growth and mass accumulation
  - Can eat algae, plant wastes, and wastes from other foods
  - Tolerant of varying chemical conditions and temperatures
  - Can be crowded tightly
- Best to marry to the right crops in hydroponics and especially to photobioreactors.

Thank You for Coming!
And remember:
Why do we settle space?

Trillions of Happy, Smiling Babies!

References (other then my papers)

1. http://www.fao.org/fishery/affris/species-profiles/nile-tilapia/growth/en/
2. http://www.fao.org/docrep/field/007/af011e/AF011E10.HTM
3. http://www.fao.org/docrep/005/W5268E/W5268E00.htm
4. http://www.fao.org/docrep/005/W5268E/W5268E09.htm
5. http://www.fao.org/3/y4100e/y4100e09.htm
6. https://extension2.missouri.edu/g9471
7. http://www.biomin.net/en/videos/sustainable-shrimp-farming-high-density-biofloc-dominated-no-water-exchange-systems/
8. http://www.fao.org/docrep/field/003/ac210e/AC210E08.htm
9. https://extension.purdue.edu/extmedia/EC/EC-797-W.pdf
10. http://www.fao.org/fishery/affris/species-profiles/rainbow-trout/growth/en/
11. https://www.seagrant.umaine.edu/aquaculture/resources-for-shellfish-growers/species/mussel
12. https://thefishsite.com/articles/cultured-aquatic-species-red-claw-crayfish
13. https://fisheries.tamu.edu/pond-management/species/channel-catfish/
14. https://fisheries.tamu.edu/aquaculture/catfish/
15. http://www.ksuaquaculture.org/Species/Carp,Common.htm
16. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119120759.ch2_1
17. https://ec.europa.eu/fisheries/cfp/aquaculture/species_en
18. https://www.mdpi.com/2071-1050/10/6/1805/pdf
19. http://www.fisheriessciences.com/fisheries-aqua/comparative-study-of-growth-performance-and-survival-of-african-catfish-clarias-gariepinus-burchell-1822-fry-in-indoor-and-outdoor.php?aid=8213
20. http://www.bioline.org.br/pdf?ja09004
21. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5585874/
22. www.fao.org/fileadmin/user.../fisheries/docs/The_Value_Chain_of_African_Catfish.ppt
23. http://www.fao.org/3/a-ak505e.pdf
24. https://vtechworks.lib.vt.edu/handle/10919/36593