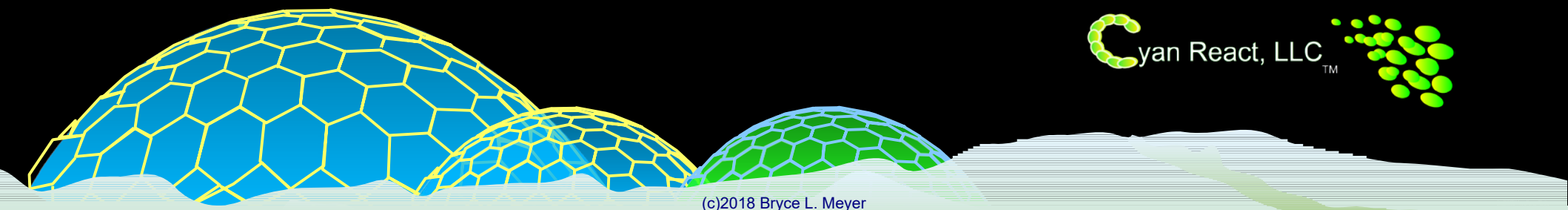
National Space Society
International Space Development Conference®

What's My Dinner? Evolution of Recycling Space Farms and Menus for a Space Settlement.

by Bryce L. Meyer
24 May 2018



Cyan React, LLC™

Settlement / Resort Level	Space Equiv.	Earth Analog (Resort)	Earth Analog (Settle-ment)	Food Source	Recycling and Farming
0/0	ISS as of 2017, all space outposts to 2017.	Everest Base Camp	Remote Outpost	All from Earth	Minimal Chemical Recycling of gases and water. A few ornamental plants. Requires extensive resupply.
0/1	Inflatable or Basic Orbital Unit/Hotel	Oil Rig, Antarctica Bases.	Remote Outpost	All from Earth	Minimal Chemical Recycling of gases and water. Plants as or- namental compliment to diet. Requires extensive Resupply
0/2	Begin- ning Space Resort	Hotel with amenities .	Camp/ Hotel with Garden (no families)	Most from Earth, some local	Some biological recycling of sol- ids, and full recycling (biologi- cal/mechanical) of gases and water. Some hydroponic growth. Minimal bioreactors. Requires import for Complex menus.
1/3	Next Level Space Resort	Major Hotel/ Resort (Cruise Ship destination/ provision)	Farming Transient Town (few families).	Some items Earth, though sta- ples and spice items local.	Complete recycling of solids, liq- uids, gases. Hydroponics and bioreactors, minimal animal (aquatic or insect). Complex menus combining local sources, with luxury items from off-site
2/4A	Full Space Resort as part of a small set-tlement.	All inclusive luxury resort as part of a community.	Permanen t Growing Town	Majority of foods local. Self Sufficient for all but guests and children. Ac- cess to some in-situ or local supplies.	Complete recycling of solids, liq- uids, gases, very efficiently. Hy- droponics, some in-soil in Habi- tat growth, and bioreactors, many aquatic species (fish, shrimp). Complex menus from local sources, though some re- supply for luxury items and inef- ficiencies.
3/4B	Full Space Resort as part of a growing settle-ment	All inclusive luxury resort as part of a community and city. Many off resort options.	Permanent Large Growing Town/Cit y with food exports.	Self Sufficient for all but guests and extra pop growth and export. Access to re-sources for excess pro-duction. Part of an economic trade web.	Complex farms (either staged or 'open' air) with diverse species, including crop species for export. Mass flow is efficient for productive farm. Parks with extensive in-soil planting, including limited tree and bush crops and ornamental plants.

Assumptions

- Energy is plentiful, mass is not.
- Spices and Herbs can be grown in habitats with people, as houseplants, using gray water.
- Kitchen is very efficient, and can store foods for up to 1 year.
- Assume minimal, low mass resupply, and high use of in situ materials to construct the farm.
- Assume a year between scenarios.

Farm Concept: Stages

Each Stage is a combination of machinery and enclosures to optimize productivity for the organisms.

Four Stage Types:

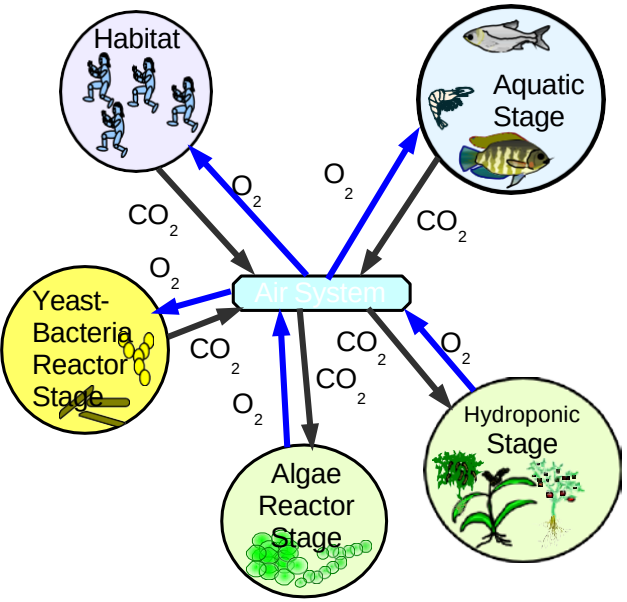
.**Aquatic:** A series of raceways or tanks for fish or shrimp

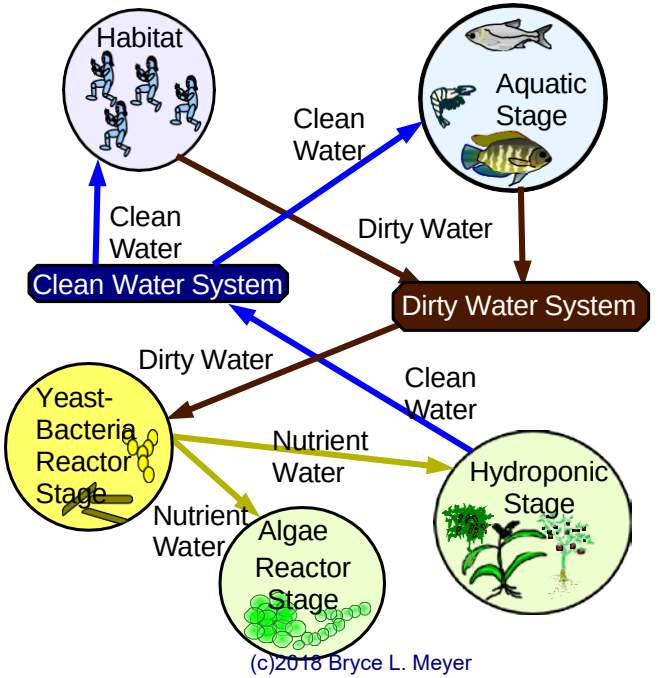
.**'Hydroponic':** Hydroponic/Aeroponic/Aquaponic beds, with aerated root beds and carbon-dioxide rich atmosphere, lit by LED lights at optimal distance and spectra, for growing vascular plants.

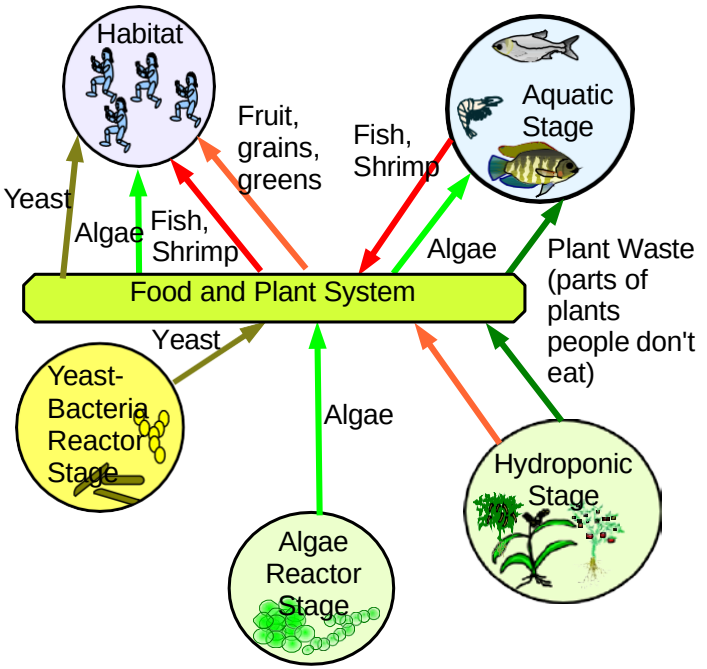
.**Photobioreactors (Algae Reactors):** Membrane or open frame mediated liquid environments with lighting, to grow algae, cyanobacteria, or other water plants.

.**Yeast-Bacteria (Aerobic or Anaerobic) Bioreactors:** Membrane or open format series of bioreactors seeded with combinations of bacteria and yeast, controlled to produce chemical outputs and yeast products. CONVERTS CELLULOSE TO CARBON DIOXIDE!

.Farm Stages and the Human Habitat are linked to make an artificial ecosystem cycle.







Farm Scenario Examples

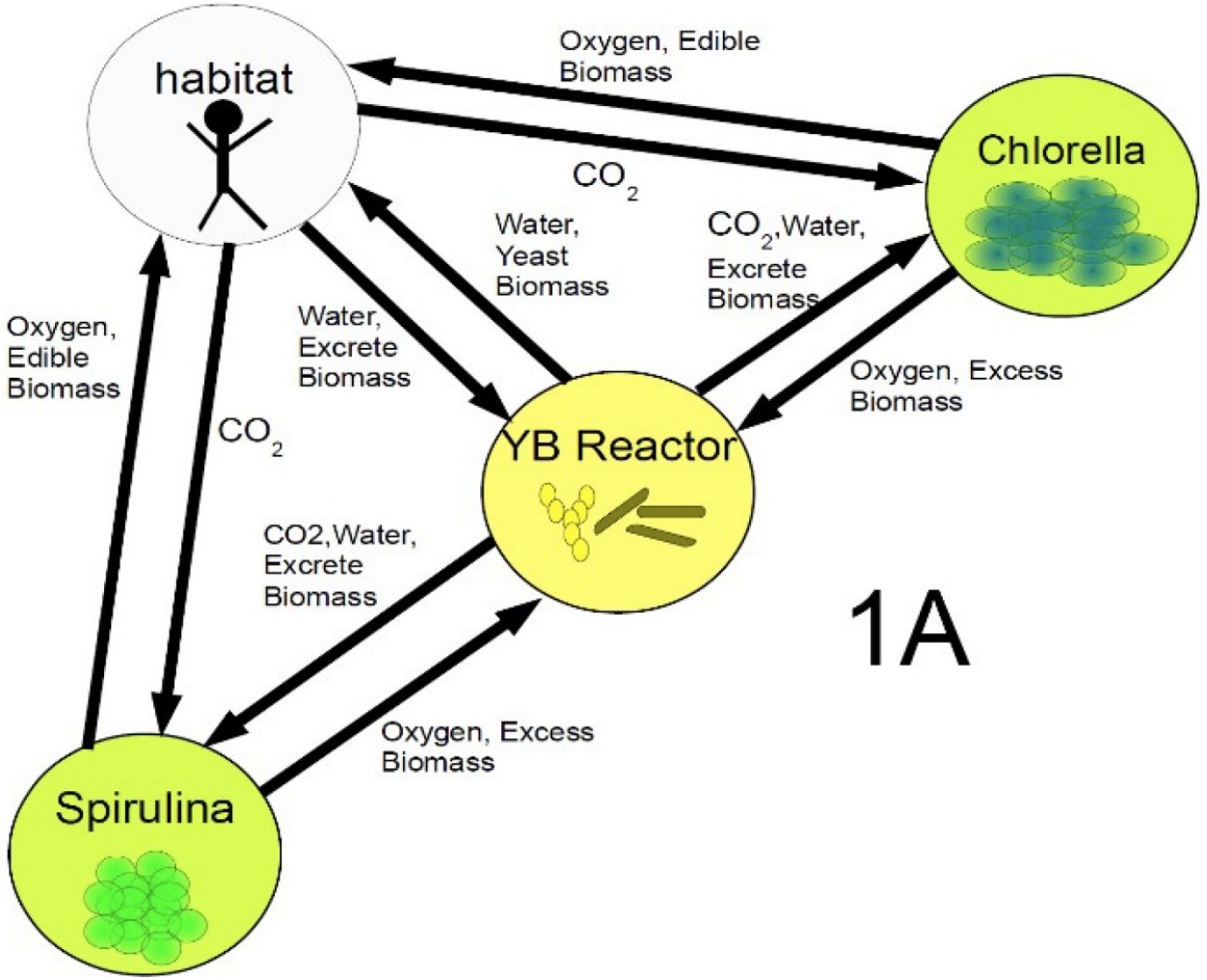
- Calculated 6 scenarios to get a mass balanced farm. 3+4 have the same dietary options.

SPECIES	STAGE TYPE	SCENARIO				
		1A	1B	2A	2B	3+4
Barley	Hydroponic					X
Bell Peppers	Hydroponic			X	X	X
Chlorella	Algae Reactor	X	X	X	X	X
Pinto Beans	Hydroponic			X	X	X
Potatoes	Hydroponic			X	X	X
Rice	Hydroponic				X	X
Shrimp	Aquatic					X
Silver Carp	Aquatic					X
Soybeans	Hydroponic					X
Spirulina	Algae Reactor	X	X	X	X	X
Tilapia	Aquatic			X	X	X
Tomato	Hydroponic		X	X	X	X
Yeast-Bacteria Reactor	Yeast-Bacteria Reactor	X	X	X	X	X

Nutrients by crop

	Nutrient Composition (kg) by living kg crop edible biomass						
Species	**Kcal per kg**	**Carbohydrate***	**Fats**	**Proteins**	**Fiber**	**N***	**S***
Barley	3540	56.18%	2.30%	12.48%	17.30%	1.60%	0.12%
Bell Peppers	270	5.42%	0.21%	1.00%	0.90%	0.13%	0.01%
Chlorella	383	2.27%	0.91%	5.71%	0.03%	0.82%	0.06%
Pinto Beans	3470	47.05%	1.23%	21.42%	15.50%	2.92%	0.12%
Potatoes	770	15.46%	0.09%	2.05%	2.03%	0.26%	0.01%
Rice	3570	71.00%	1.02%	13.29%	5.88%	1.89%	0.13%
Shrimp	850	0.00%	0.51%	20.04%	0.00%	2.95%	0.48%
Silver Carp	1270	0.00%	5.57%	17.10%	0.00%	2.48%	0.16%
Soybeans	1470	6.85%	6.80%	12.95%	4.20%	1.80%	0.07%
Spirulina	260	2.02%	0.39%	5.99%	0.40%	0.89%	0.60%
Tilapia	960	0.00%	1.70%	19.87%	0.00%	2.86%	0.19%
Tomato	180	2.63%	0.20%	0.88%	1.26%	0.11%	0.00%
Yeast from Yeast-Bacteria Reactor	773.5	3.59%	1.91%	10.14%	6.74%	1.39%	0.08%
HUMAN NEED (kcal or kg)	**2000**	**0.32**	**0.07**	**0.05**	**0.03**	**0.01**	N/A

Scenario 1A



- Limited to outputs of bioreactors, and maybe a few quick growing spices kept in habitat, or brought by resupply.
- Realistically, likely to incorporate some long storage rations.

Scenario 1A

- Initial Level: i.e. The time till you get the rest of the crops. Like a Level 0 to 1 Settlement.
- This farm has 7kg live mass in it per person, producing ~3.5 kg raw crop per day per person.
  - Algae dries to 1/10th of mass. Yeast to 1/4th dry, though for recipes it may be good to leave all partially hydrated.
  - Herbs that grow well in habitat, quickly:
    - Basil ~75 days (leaves and stems)
    - Cilantro ~30 days (leaves and stems)
    - Dill ~90 days (seeds)
    - Marigold (calendula) ~70 days (dried flowers)

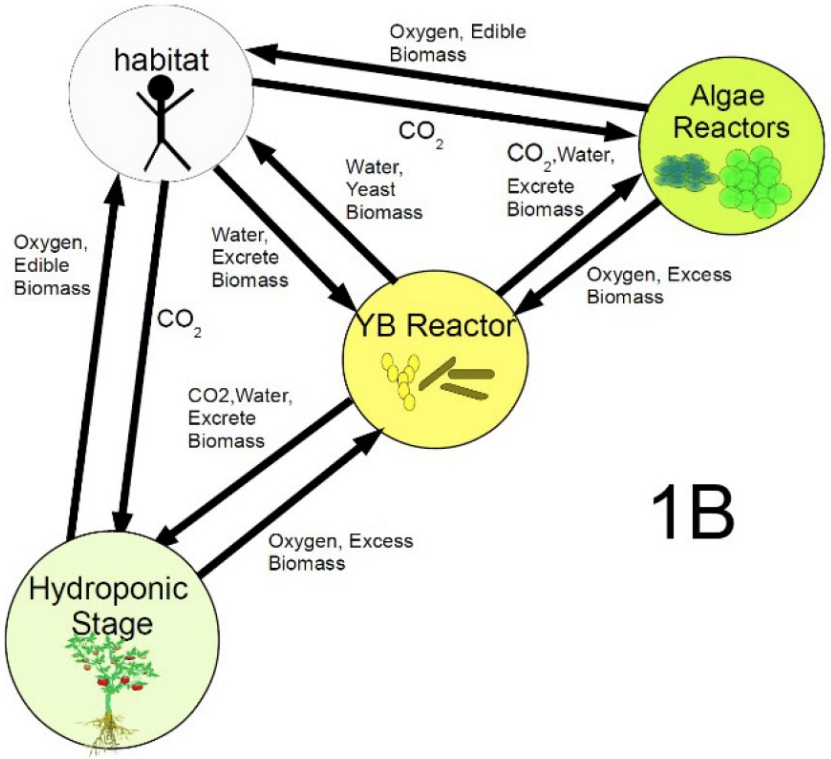
		Per person		For 100 settlers	
Species	**Stage Type**	**L_{tot}**	**L_{crop}**	**L_{tot}**	**L_{crop}**
Chlorella	Algae Reactor	3	2.2	300	220
Spirulina	Algae Reactor	3	0.75	300	75
Yeast	Yeast-Bacteria Reactor	1	0.5	100	50
		Live kg	Live kg	Live kg	Live kg

Scenario 1A Prep Options

- Make yeast and algae bars, cakes, protein drinks (ugh).
- Ferment algae using yeasts to make algae wine/kombacha.
  - At least you might feel good...no bittering agent for now (takes at least a year to get a good hop plant). No malts either, though yeast can provide the correct enzymes.
- Soups:
  - Algae strips and powders as base, yeast for clumps of protein, and yeast dried as flavoring. Spice with herbs.
- Turn dried algae films into a salad...extract oils from algae for dressings.
- Use chemistry to extract sugars, proteins to other processed foods?
- 3D Printing to make palatable shapes? Waffles? Gummy chews (due to agar in algae)?

Scenario 1B

- Still Initial Settlement (Level 0 to 1)
- Same as scenario 1A except with a hydroponic stage (with Tomatoes) Similar to ISS.
- Assume same spices, but add a few more:
  - Mint ~90 days
  - Taragon ~60 days.
  - Ginger ~200 days



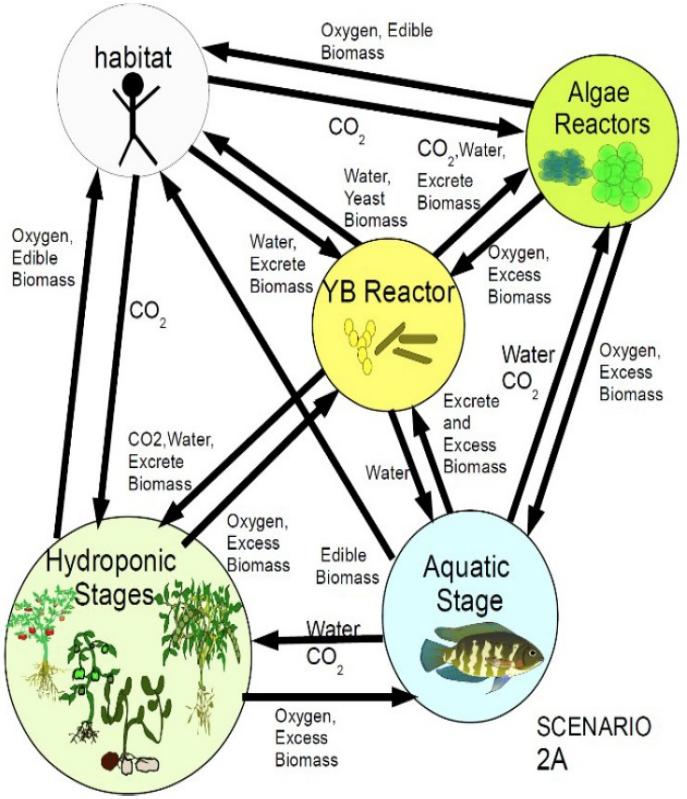
		Per person		For 100 Colonists	
Species	**Stage Type**	**L_{tot}**	**L_{crop}**	**L_{tot}**	**L_{crop}**
Chlorella	Algae Reactor	3	2	300	220
Spirulina	Algae Reactor	1	0.25	100	25
Yeast	Yeast-Bacteria Reactor	0.5	0.25	50	25
Tomato	Hydroponic	15	14	1500	1364
		Live kg	Live kg	Live kg	Live kg

Scenario 1B Prep Options

- Since you have LOTS of tomatoes:
  - Tomato Salads flavored with dried yeast and algae.
  - Ferment Tomatoes to get wine and vinegar.
    - Vinegar opens up many recipe options.
    - Wine would be very like a veggie drink or Bloody Mary.
  - Make noodles from algae and yeast.
    - Extract oils from algae, use vinegar and tomatoes to make many noodle and noodle bowl dishes.
  - Sauces:
    - Given spices, a marinara could be made. Make 'meatballs' from yeast.
  - Vinegar from tomatoes, and oils from algae can be used to make salad dressings and dips.

Scenario 2A

- Sustained Settlement (Settlement Level 1)
- Added crops in Hydroponic Stages: Bell Peppers, Pinto Beans, Potatoes.
- 2A has a very small Aquatic Stage with Tilapia.
- Possibly a very small in habitat grow of Serrano Peppers?



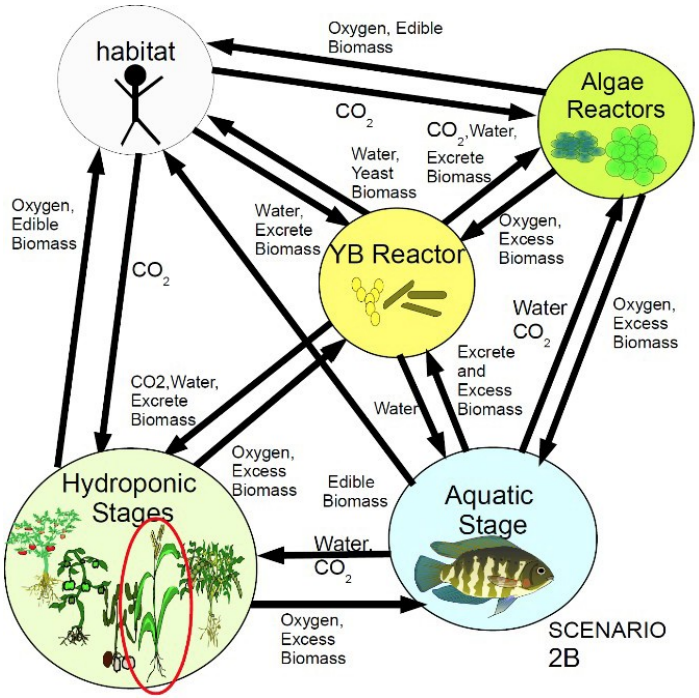
		Per person		For 100 Settlers	
Species	**Stage Type**	**L_{tot}**	**L_{crop}**	**L_{tot}**	**L_{crop}**
Bell Peppers	Hydroponic	16	1	1,600	77
Chlorella	Algae Reactor	14	10	1,400	1,027
Pinto Beans	Hydroponic	32	1	3,200	136
Potatoes	Hydroponic	92	7	9,200	697
Spirulina	Algae Reactor	7	2	700	175
Tilapia	Aquatic	2	0	200	12
Tomato	Hydroponic	30	27	3,000	2,727
		Live kg	Live kg	Live kg	Live kg

Scenario 2A Prep Options

- Drinks: In addition everything before, we can now ferment and distill potatoes to get vodka. You can almost make a passible bloody mary.
- Potatoes can be turned into sweeteners for desserts (with addition of amalyse). Potatoes can be dried into a flour for breads.
- A wide variety of Mexican and Asian foods can be made given the addition of less than a kg of fish, peppers, and beans.
  - Stuffed Bell Peppers with yeast and tomatoes, beans.
  - Bean Chili using Serrano pepper powder, tomatoes, bell peppers, etc?
  - Bean Tortillas, Algae Tortillas and wrappers?
- Tilapia fillets yes for the very few fish harvested, but tilapia fish meal can be fermented to get fish sauce (assuming salt). Remember I only get a few tilapia for 2A (12 kg for 100 settlers/ day).

Scenario 2B

- Sustained Settlement (Settlement Level 1)
- Sames as 2A but with a hydroponic grain (Rice) and more Tilapia (0.24 kg/day/person).



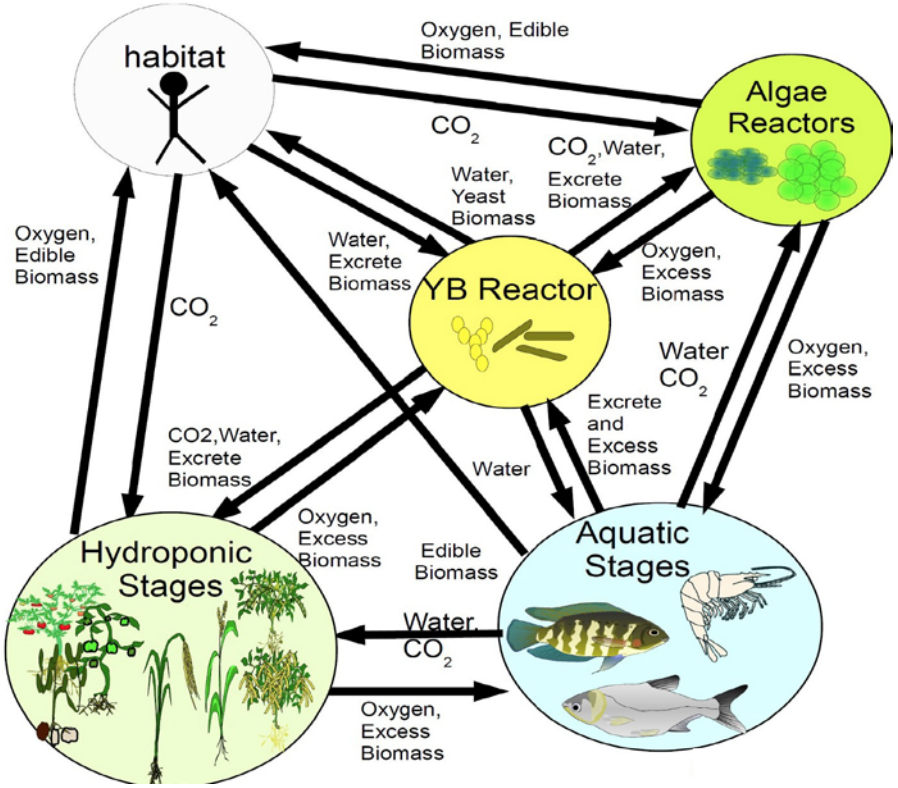
		Per person		For 100 Settlers	
Species	**Stage Type**	**L_{tot}**	**L_{crop}**	**L_{tot}**	**L_{crop}**
Bell Peppers	Hydroponic	14	0.67	1400	67
Chlorella	Algae Reactor	9	6.6	900	660
Pinto Beans	Hydroponic	17	0.72	1700	72
Potatoes	Hydroponic	5	0.38	500	38
Spirulina	Algae Reactor	4	1	400	100
Tilapia	Aquatic	4	0.24	400	24
Tomato	Hydroponic	20	18.18	2000	1818
Rice	Hydroponic	21	0.7	2100	70
		Live kg	Live kg	Live kg	Live kg

Scenario 2B Prep options

- As in all previous scenarios, but adding more options:
- Rice allows production of vinegar, rice wine/sake, Mexican horchata. By this stage you have grown hops, though ginger could work as bittering agent.
- Concentrated rice and potatoes can be made into sweeteners for desserts.
- Rice also allows expansion into rice-based cuisines, pilafs, and breads.
  - Rice flour muffins for one. Better wraps and tortillas.
  - Combined rice/potato pastries, breading.

Scenario(s) 3 (+4)

- Steady State Settlement (Settlement Level 2)
- Many seafood options with tilapia, silver carp, and shrimp.
- Added plants: Barley, Soybeans.



		Per person		For 100 Settlers	
Species	**Stage Type**	**L_{tot}**	**L_{crop}**	**L_{tot}**	**L_{crop}**
Barley	Hydroponic	50	0.67	5000	67
Bell Peppers	Hydroponic	23	1.11	2300	111
Chlorella	Algae Reactor	5	3.67	500	367
Pinto Beans	Hydroponic	20	0.85	2000	85
Potatoes	Hydroponic	14	1.06	1400	106
Rice	Hydroponic	7	0.23	700	23
Shrimp	Aquatic	34	2.58	3400	258
Silver Carp	Aquatic	30	0.75	3000	75
Soybeans	Hydroponic	54	1.44	5400	144
Spirulina	Algae Reactor	5	1.25	500	125
Tilapia	Aquatic	10	0.61	1000	61
Tomato	Hydroponic	14	12.73	1400	1273
		Live kg	Live kg	Live kg	Live kg

Scenario 3+4 Prep Options

- All previous options plus many new options.
- Barley makes soups, flour, and real beer. Sprouting barley makes malt for beers and other drinks (malted soymilk shakes?).
- Soybeans add tofu, edamame, soy sauce, and possibly sprouts.
  - Soymilk, etc.
  - Soybeans are an easy source of oils, and powders.
    - Fried fish, shrimp are on the menu.
- Rice flour+soy oil+ yeast = donuts

Overall Herbs and Spices

- Herbs and Spices can also be grown in habitat as ornamental plants, because they smell good, recycle carbon dioxide, and can use gray water.
- In Habitat grown potted plants, or as hydroponic crops:
  - Sage
  - Basil
  - Mint
  - Oregano
  - Garlic
  - Saffron
  - Ginger
  - Tumeric
  - Corriander
  - Thyme
  - Chive
  - Rosemary
  - Cumin
  - Paprika
  - Fennel
  - Mustard
  - Hops (need 2 years)

FYI..given time (2-3 years) you could grow COFFEE and TEA as potted or hydroponic crops

- Unfortunately some common items are more difficult, requiring recipe adaptation:
  - Olives
  - Cinnamon
  - Black Pepper
  - Nutmeg
  - Cocoa

Space Menu, Scenarios 3+4 (assume 3 year old settlement)

- Example Breakfast:
  - Drink options: Soymilk, Barley Malt, Ginger tea, and some coffee (as an upgrade), horchata, bloody mary.
  - Puffed Malted cereal, puffed rice cereal, barley porrige with beans, steamed sweet rice w/ginger.
  - Soy egg substitute, soy-cheese, fried tilapia or carp, refried beans.
  - Rice or potato pancakes with rice/potato syrup, mustard sauce, catsup, and/or soy margarine.
  - Rice flour muffins, potato bread.
  - Fried potatoes.
  - Fresh tomatoes.

Space Menu, Scenarios 3+4 (assume 3 year old settlement)

- Example Lunch/Dinner:
  - Drink options: as for breakfast, plus full vodka bar, wines (algae, potato, rice), beer, kombacha. Fried,
  - baked, steamed, breaded or not, fish or shrimp. With or without beans, rice, and tortillas.
    - Fish or soy sausages.
  - Bean Burritos w/soy-cheese, rice, peppers.
  - Noodle bowls: pick vegetables and proteins.
  - Spaghetti with soy or fish 'meatballs'. Fettuccine with shrimp and soy-alfredo.
  - Sushi and Sashimi plate of tilapia, cooked shrimp rolls, carp rolls.

Conclusion

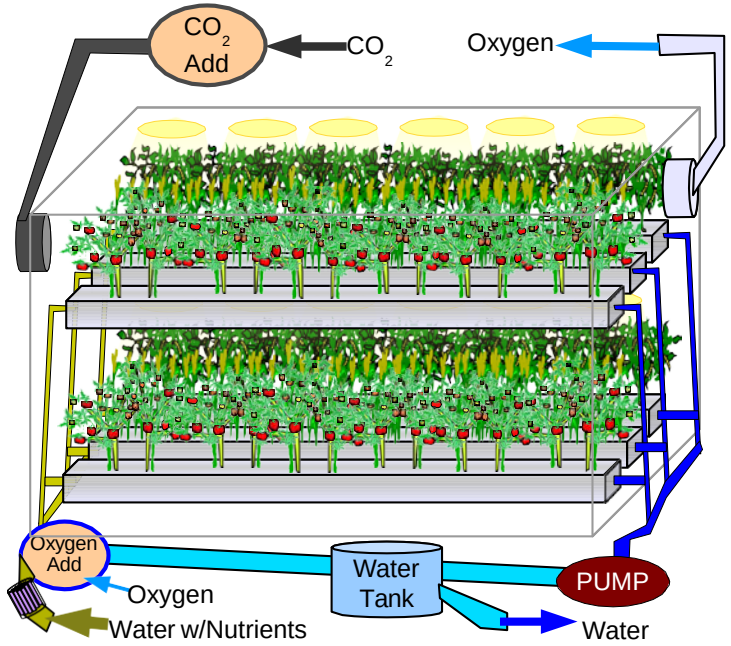
- As settlements/space farms grow, more dietary options are available, and better menus.
  - Early farms will see very limited ingredients.
  - Very important to grow herbs and spices in habitat from gray water to add options (and make the air smell nice).
  - Some spices will need to be imported.
  - Later settlements farm produce can be combined with spices (or added hydroponic grows for spices and coffee, etc.)
- See NSS Jounal paper for farm technical details for each scenario.

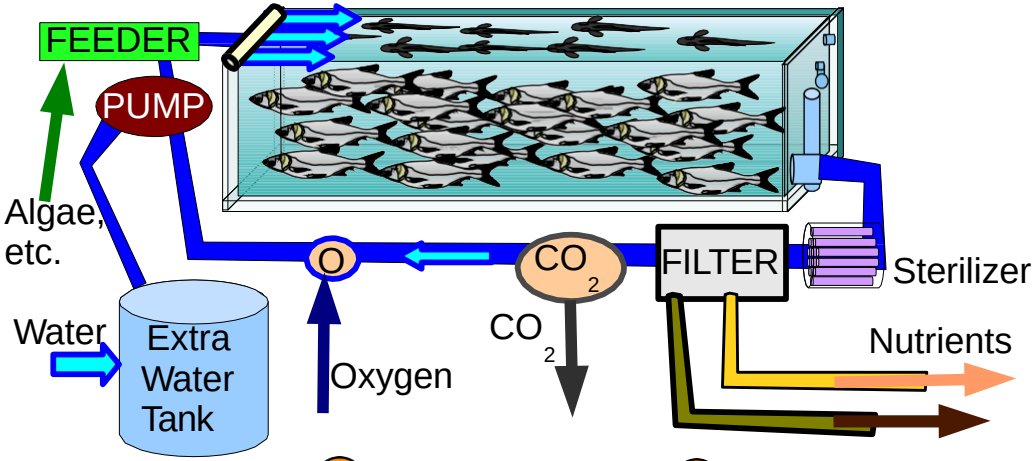
REFERENCES

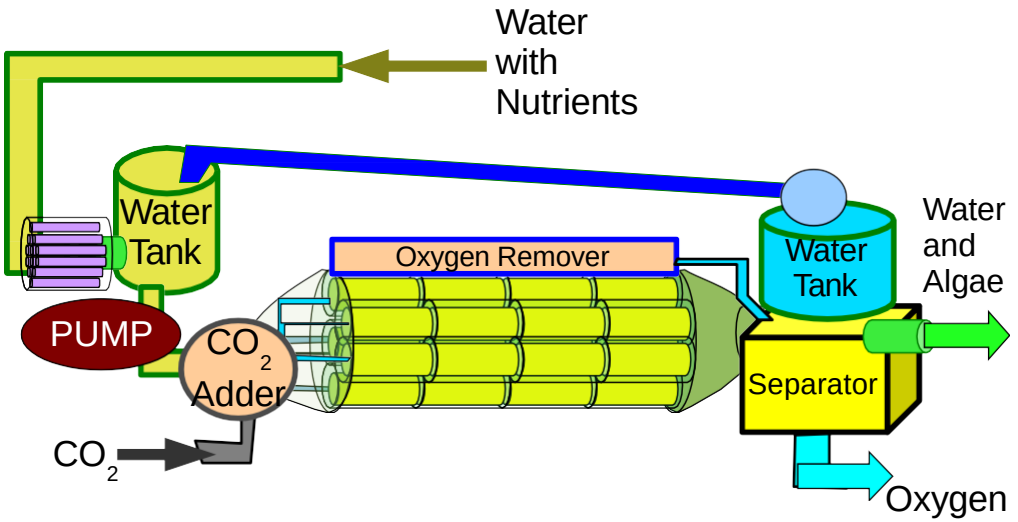
1. "Mass and Volumes for a Spectrum of Multistage Evolving Space Farms." Bryce L. Meyer, *NSS Space Settlement Journal*, Issue #3, Nov 2017.
2. Wikipedia (for each spice and herb).
3. Plant growth data via Burpee site at: *https://www.**burpee**.com*

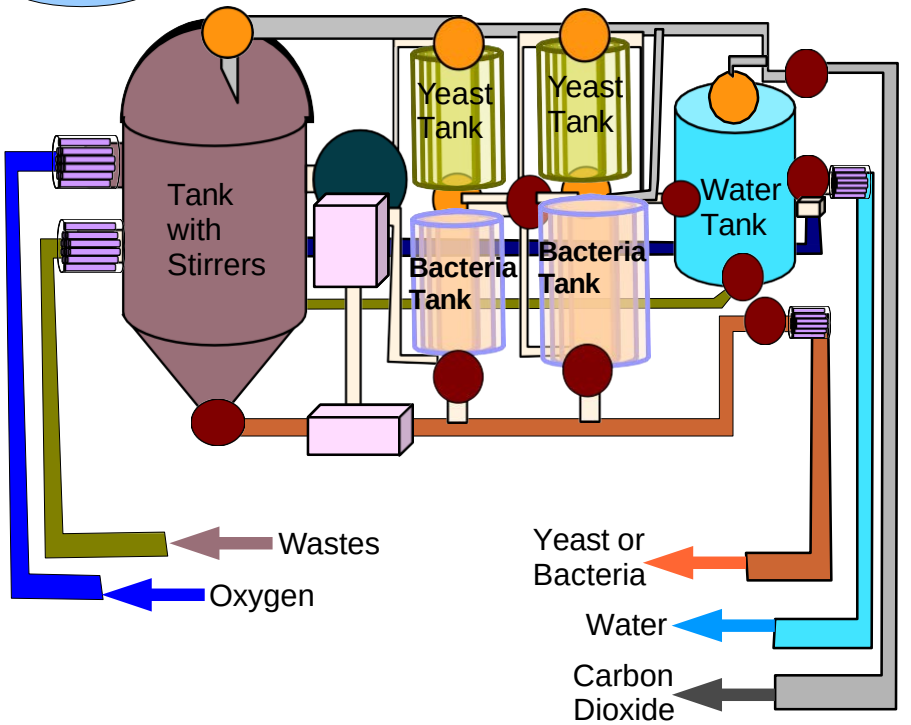
BACKUPS

Farm Stages





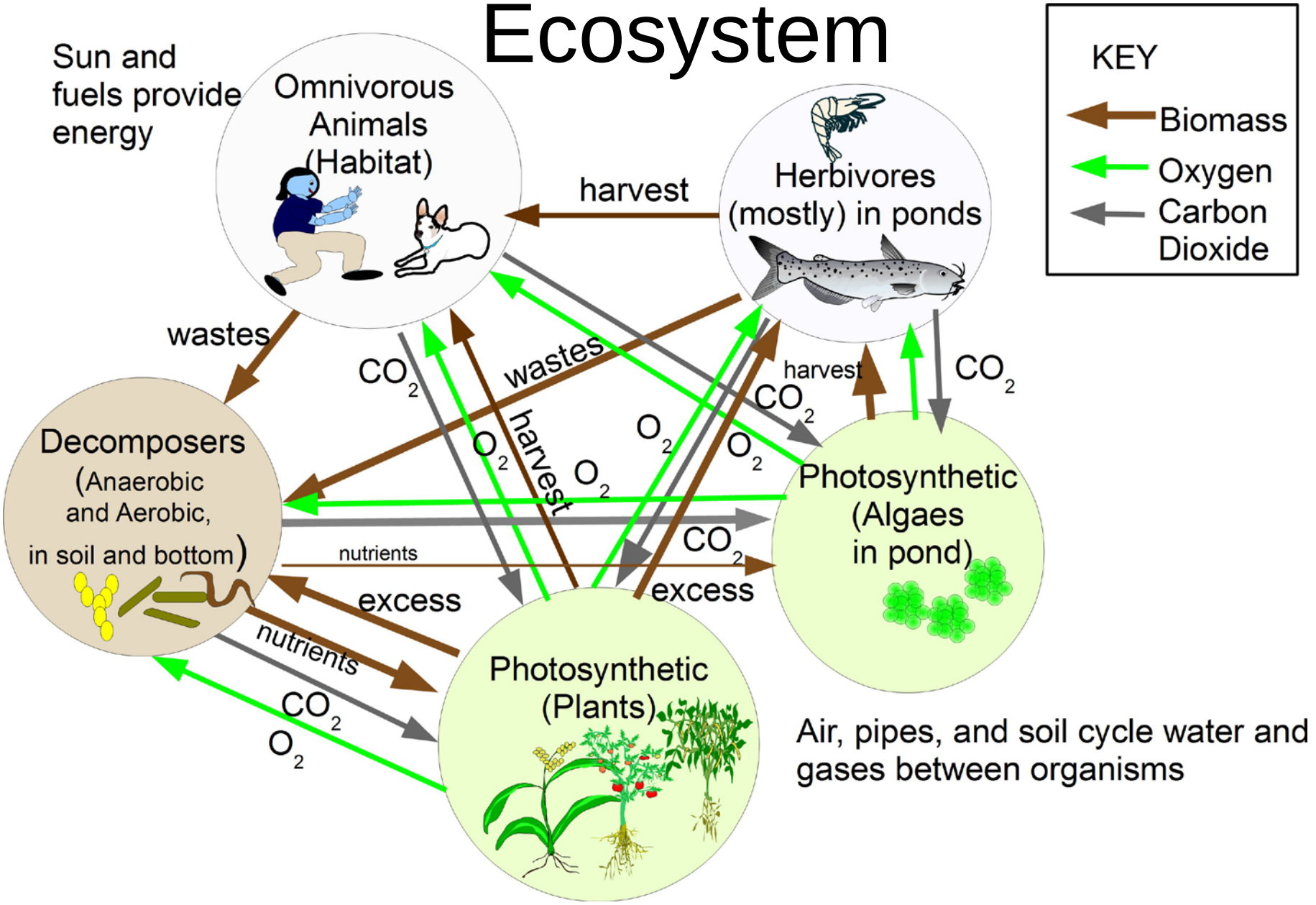




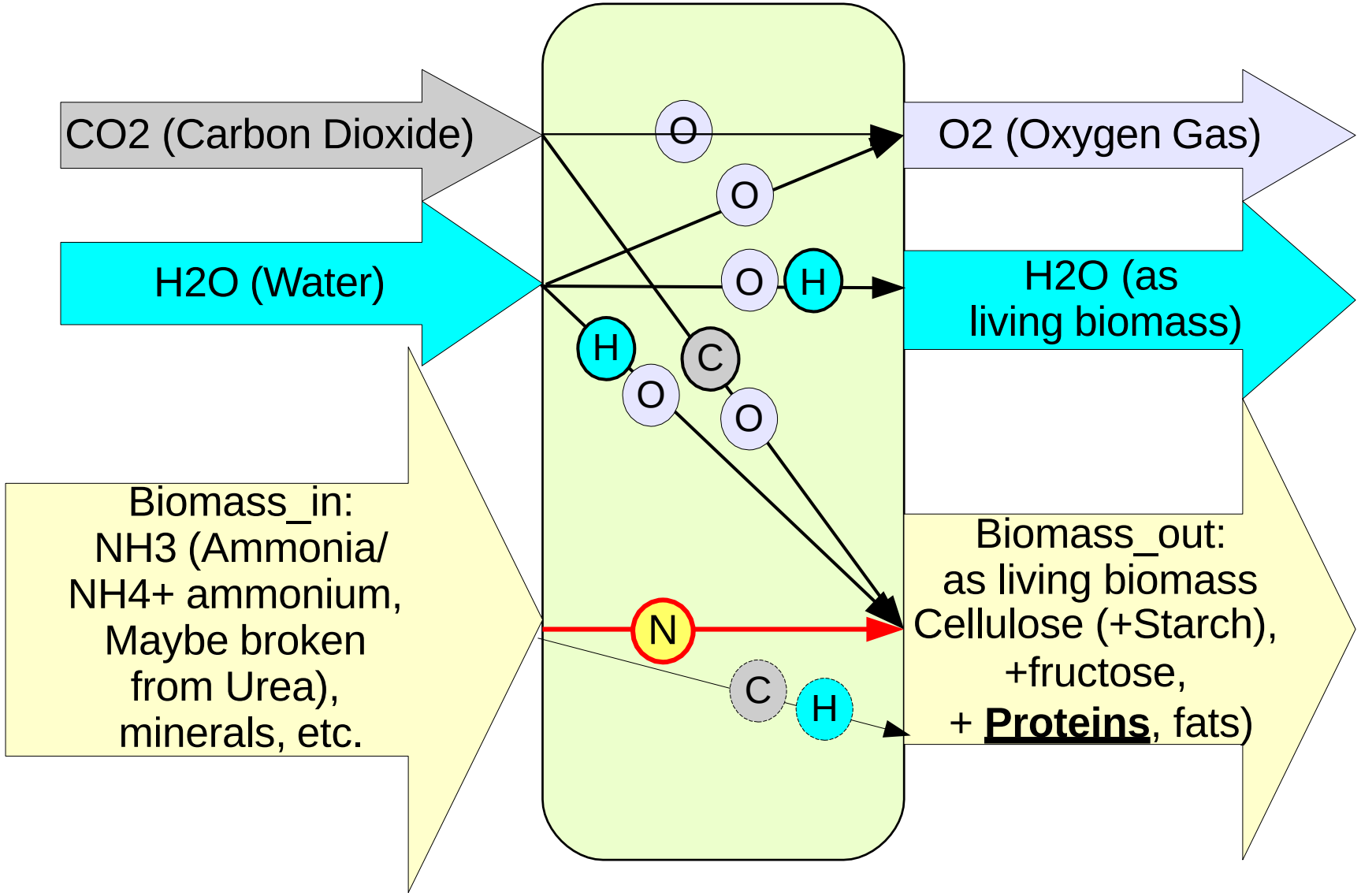
If you had to eat just one...ugh!

	Minimum edible biomass (in kg raw food) to meet USRDA Minimums						Worst Case
species	**Kcal**	**Carbohydrate***	**Fats**	**Proteins**	**Fiber**	**N***	
Barley	0.56	0.58	3.06	0.4	0.14	0.46	3.06
Bell Peppers	7.41	5.98	33.48	5	2.78	5.48	33.48
Chlorella	5.23	14.28	7.73	0.88	85.21	0.9	85.21
Pinto Beans	0.58	0.69	5.72	0.23	0.16	0.25	5.72
Potatoes	2.6	2.1	78.11	2.44	1.23	2.78	78.11
Rice	0.56	0.46	6.87	0.38	0.43	0.39	6.87
Shrimp	2.35	N/A	13.82	0.25	N/A	0.25	13.82
Silver Carp	1.57	N/A	1.26	0.29	N/A	0.3	1.57
Soybeans	1.36	4.73	1.03	0.39	0.6	0.41	4.73
Spirulina	7.69	16.04	18.03	0.83	6.25	0.83	18.03
Tilapia	2.08	N/A	4.14	0.25	N/A	0.26	4.14
Tomato	11.11	12.32	35.15	5.68	1.98	6.77	35.15
Yeast from Yeast- Bacteria	2.59	9.02	3.68	0.49	0.37	0.53	9.02
HUMAN NEED	**2000**	**0.32**	**0.07**	**0.05**	**0.03**	**0.01**	

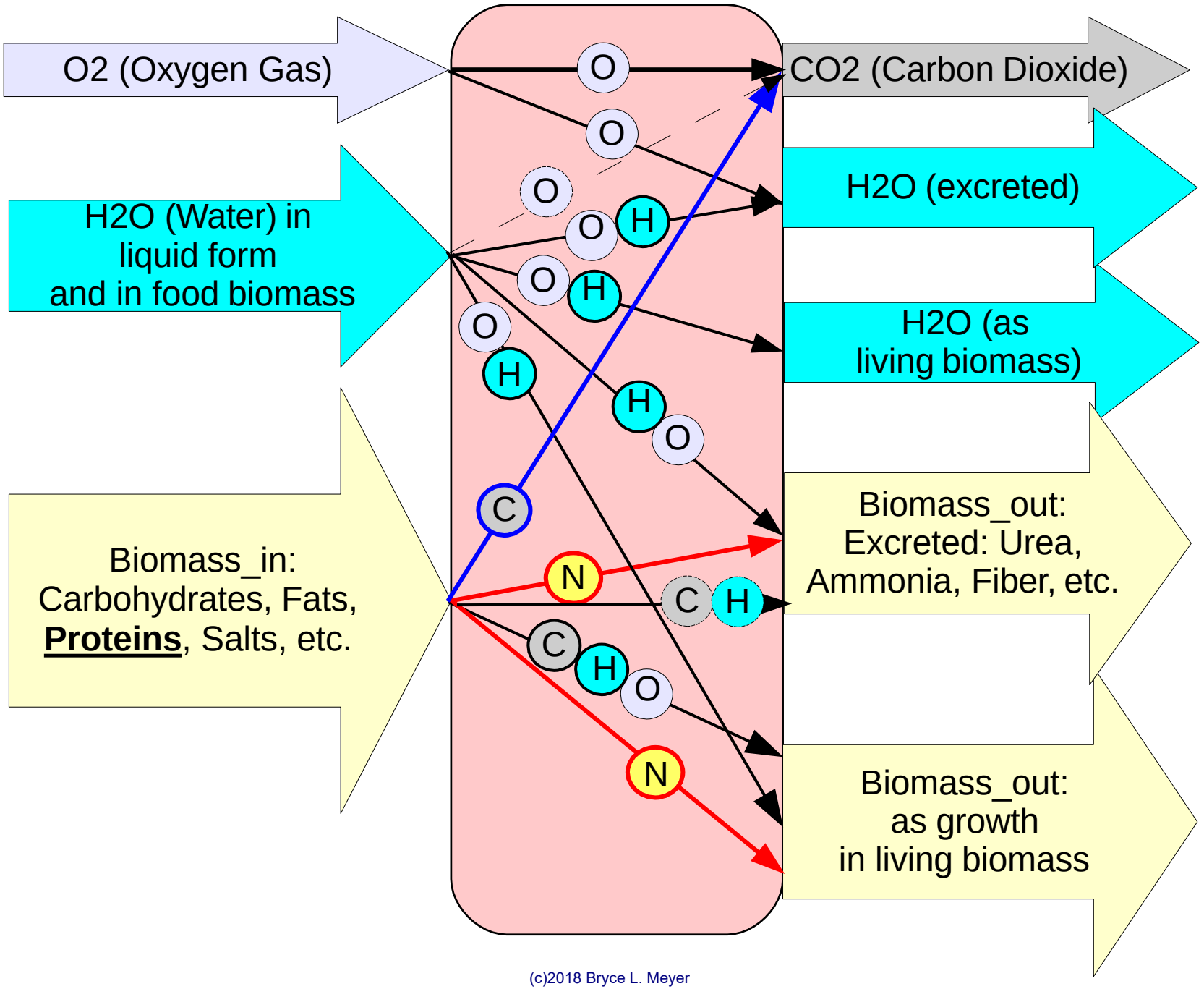
Introduction: Earth Farm as Ecosystem



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



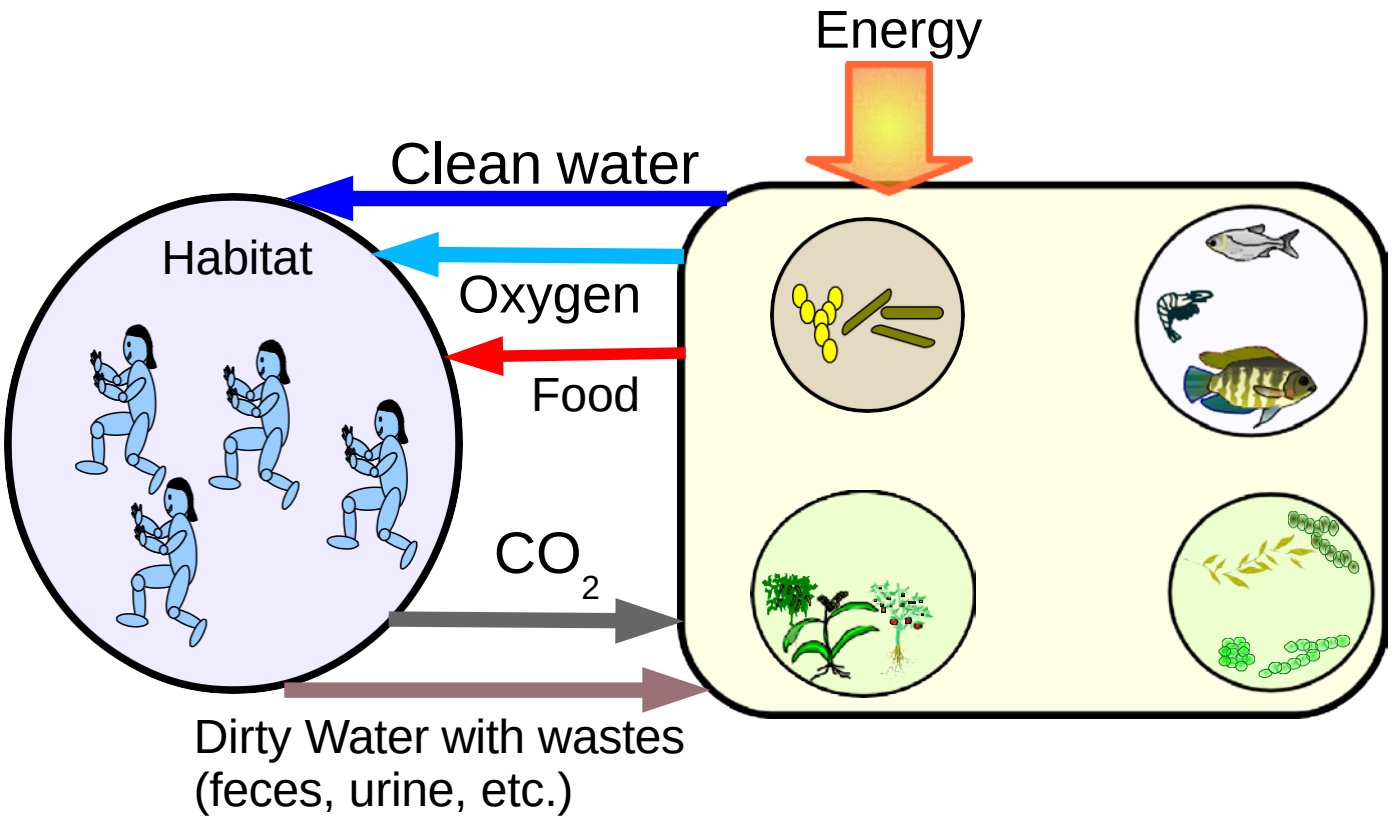
Mass Balance in Aerobic Organisms
(i.e. Yeast-Bacteria Reactor in Aerobic Mode, and Aquatics)



What is a (Recycling) Space Farm?

Space Farm: A farm in space that at a minimum recycles the outputs of a human habitat into foods, oxygen, and clean water

Mass into the Space farm = Mass out of the Space Farm



Future space farms may use local or supplied mass to produce excess foods for resturants and other settlements

Abstract

As Space Settlements evolve they will be able to provide different food options for the tourist, staff, and settler. While initial settlements will resource specialty foods from Earth while recycling air and water, later settlements will have a diversity of food options. This presentation will cover the evolving nature of food in space, but also elements of the artificial ecosystem in the space farm that recycle the air, wastes, and water of the humans, including the machinery, bioreactors, raceways, and gardens, but also the menus and foods that emerge. This presentation assumes 100 people, and uses thirteen crop species to recycle and feed the people. Also covered briefly in common terms: modelling growth in crops, core element cycles, and assumptions. How do the settlers get fresh food every day? Given foods and in habitat spices, what menus emerge? How big will the farm be as it evolves? How much initial supply will I need? All these questions will be answered here!