Space Farming, Menus, and Biological Life Support: For Here and There

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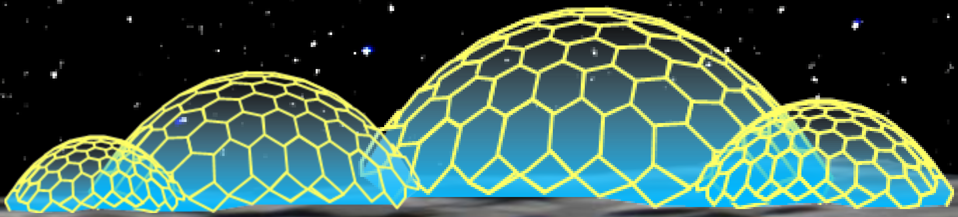
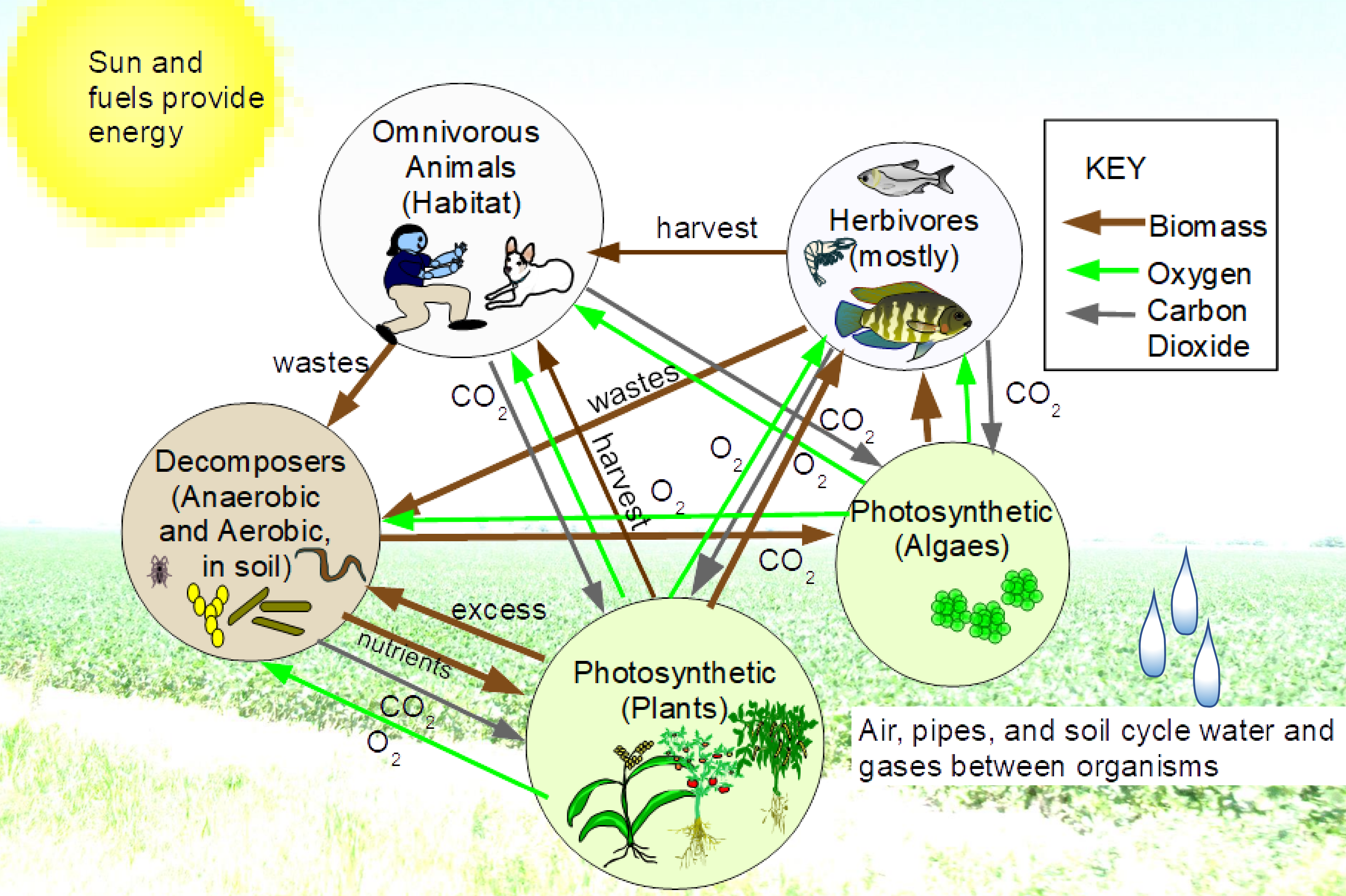
St. Louis Gateway to Space 2018



Outline

- Mass and Energy Cycle on Earth
- Life Support to Space Farming
  - Machines and Living Things
- Dinner Evolution: From Glop to Gourmet

Earth Farm Mass Flows



What do I get for ‘free’ on Earth?

- Earth farms get:
  - Carbon Dioxide, Nitrogen, and Oxygen from the air
  - Minerals from the soil
  - Water from rain, fed at the right amount in soil
  - Light for photosynthesis from the sun
  - Heating and Cooling from the air
  - In organic fields: bacteria, fungi, worms that: capture nitrogen, facilitate water to roots, and aerate soil
    - Bacteria and fungi break down cellulose in fields and forests to release carbon dioxide
  - In Ponds: algae and water plants to add oxygen and feed animals.
  - Sewage Treatment Plants/Septic Tanks: Use oxygen from the air.

Settlement Level / Resort Level	Space Equivalent	Earth Analog (Resort)	Earth Analog (Settlement)	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	Beginning Space Resort	Hotel with amenities	Camp/ Hotel with Garden (no families)	Most from Earth, some local	Some biological recycling of solids, and full recycling (biological/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)	Farming Transient Town (few families).	Some items Earth, though staples 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 settlement.	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. Access to some in-situ or local supplies.	Complete recycling of solids, liquids, gases, very efficiently. Hydroponics, some in-soil in Habitat growth, and bioreactors, many aquatic species (fish, shrimp). Complex menus from local sources, though some re- supply for luxury items and inefficiencies.
3/4B	Full Space Resort as part of a growing settlement	All inclusive luxury resort as part of a community and city. Many off resort options.	Permanent Large Growing Town/ City with food exports.	Self Sufficient for all but guests and extra pop growth and export. Access to re- sources for excess production. 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.

In Space, Nothing is Free

- Getting mass to a space settlement is expensive
  - In situ mass costs the energy to convert it.
- Volume is enclosed at a premium:
  - If a sphere: 1 cubic meter requires at least 4.8 square meters to enclose it.
  - For a 1 cm thick wall of aluminum, each cubic meter needs 130 kg of aluminum skin to enclose it.
    - Worse for cylinders, doughnuts, cubes…
- In early stage settlements, soil is not available, or takes too much room, so plants are grown w/o soil.
- Wastes, including cellulose from feces and inedible parts of plants, have to be converted to carbon dioxide, water, and nutrients.
- Everything people need should be efficiently recycled from wastes, to minimize mass inputs, in a way that minimizes volume (footprint).

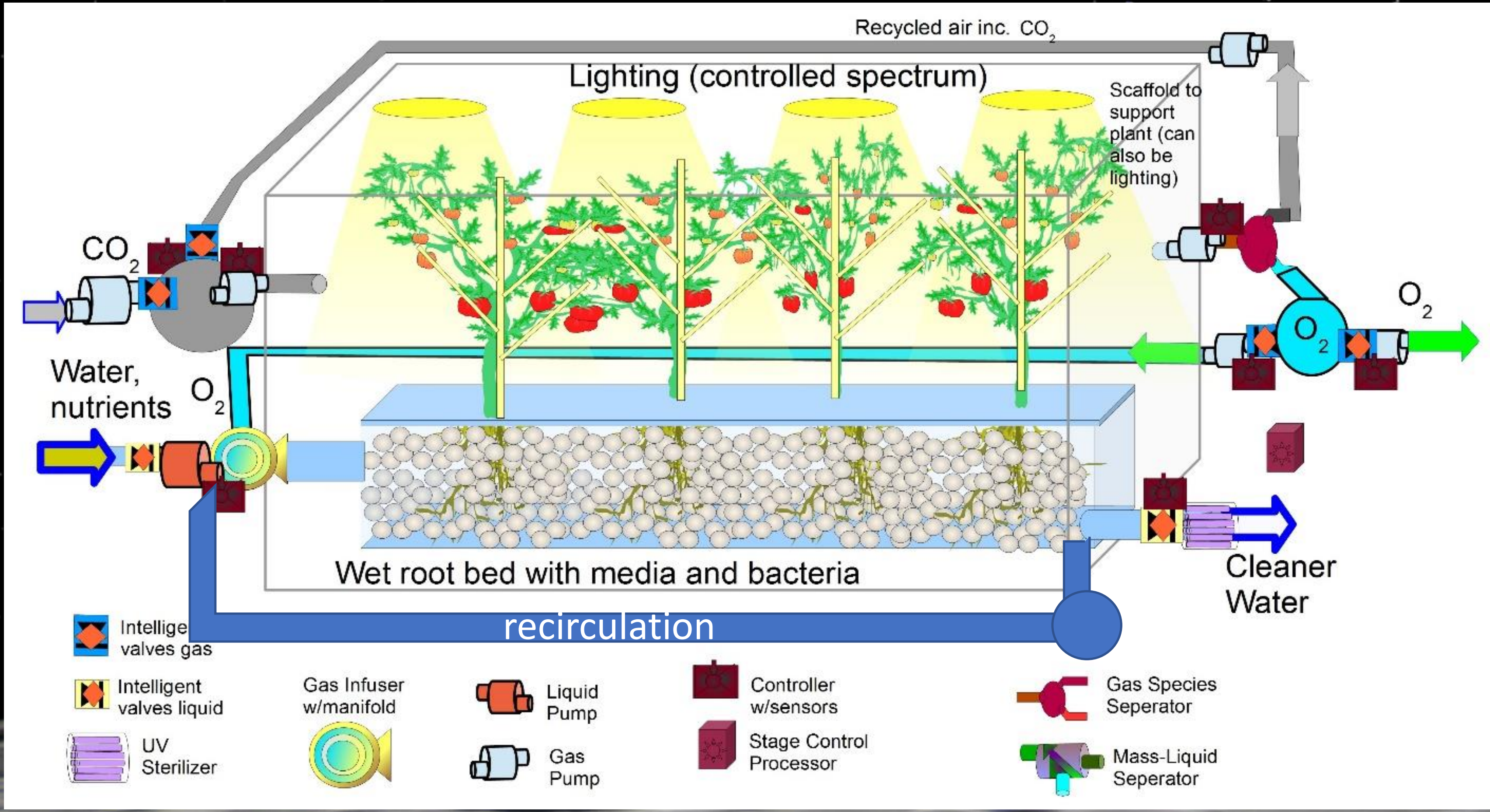
Farming in Space

Space farms must replace the mass cycles seen in the Earth farm example, except recycling everything, using machine aided analogs:

- Hydroponic Stages: Use Hydroponics (with or without root media), Aeroponics, and in very late stage farms, possibly soil, to grow vascular plants.
  - One could grow mushrooms hydroponically too.
- Aquatic Stages: Use tanks to grow fish or shrimp
  - At a minimum animals in tanks improve growth of vascular plants.
- Algae Reactor Stages: Tanks hold algae, cyanobacteria, or other water plants, with immersed and surrounding lights (i.e. a photobioreactor).
- Yeast-Bacteria Bioreactor Stage: membrane and open format bioreactors to balance the biochemistry of the farm.

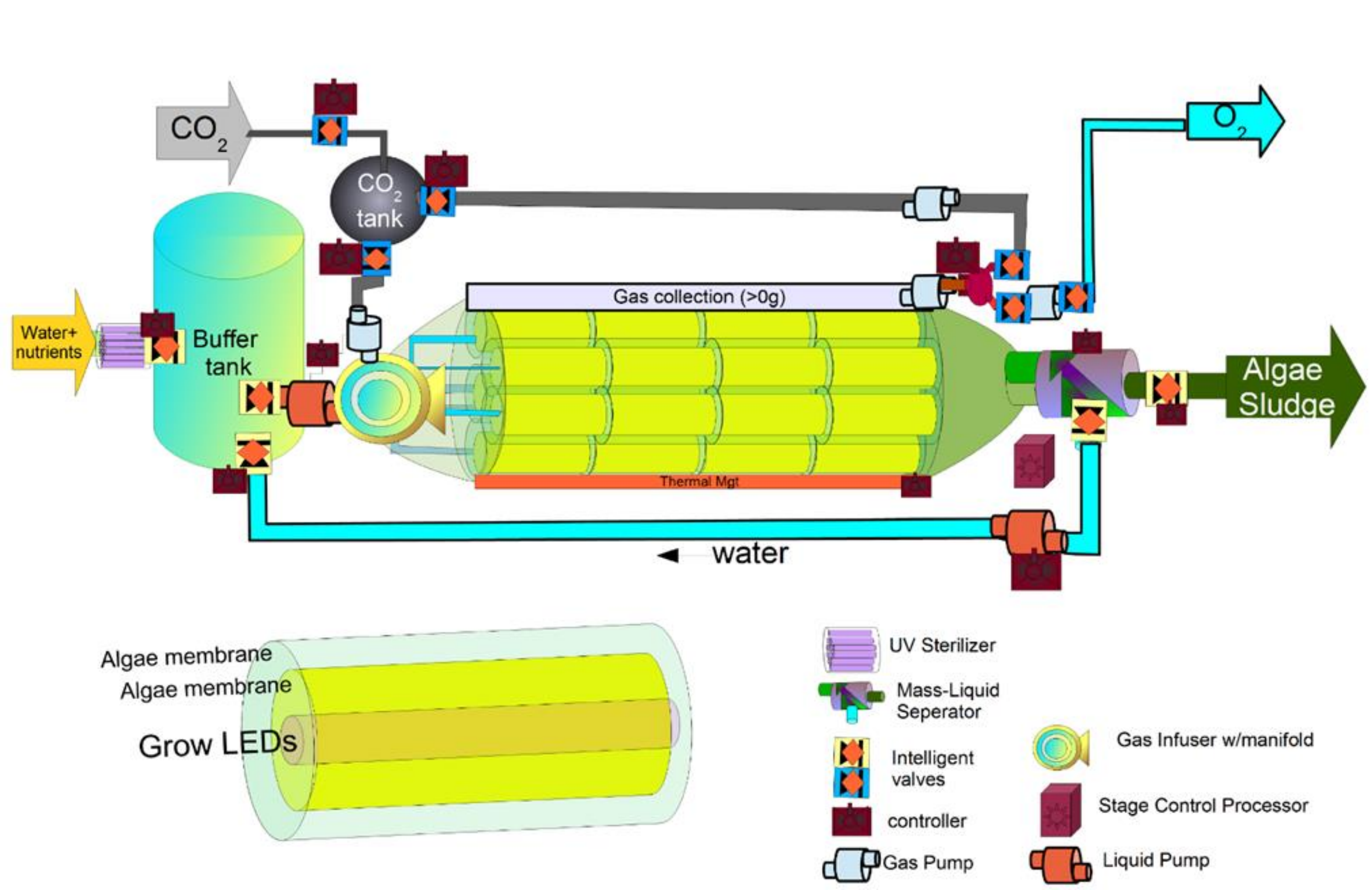
Hydroponic Stages

- Requires Lighting, Air and Liquid Pumps.
- Root bed (media or not) needs to have bacteria and fungi
- Human or Robot tending and harvest
- CO2 rich atmosphere, O2 injected into root bed



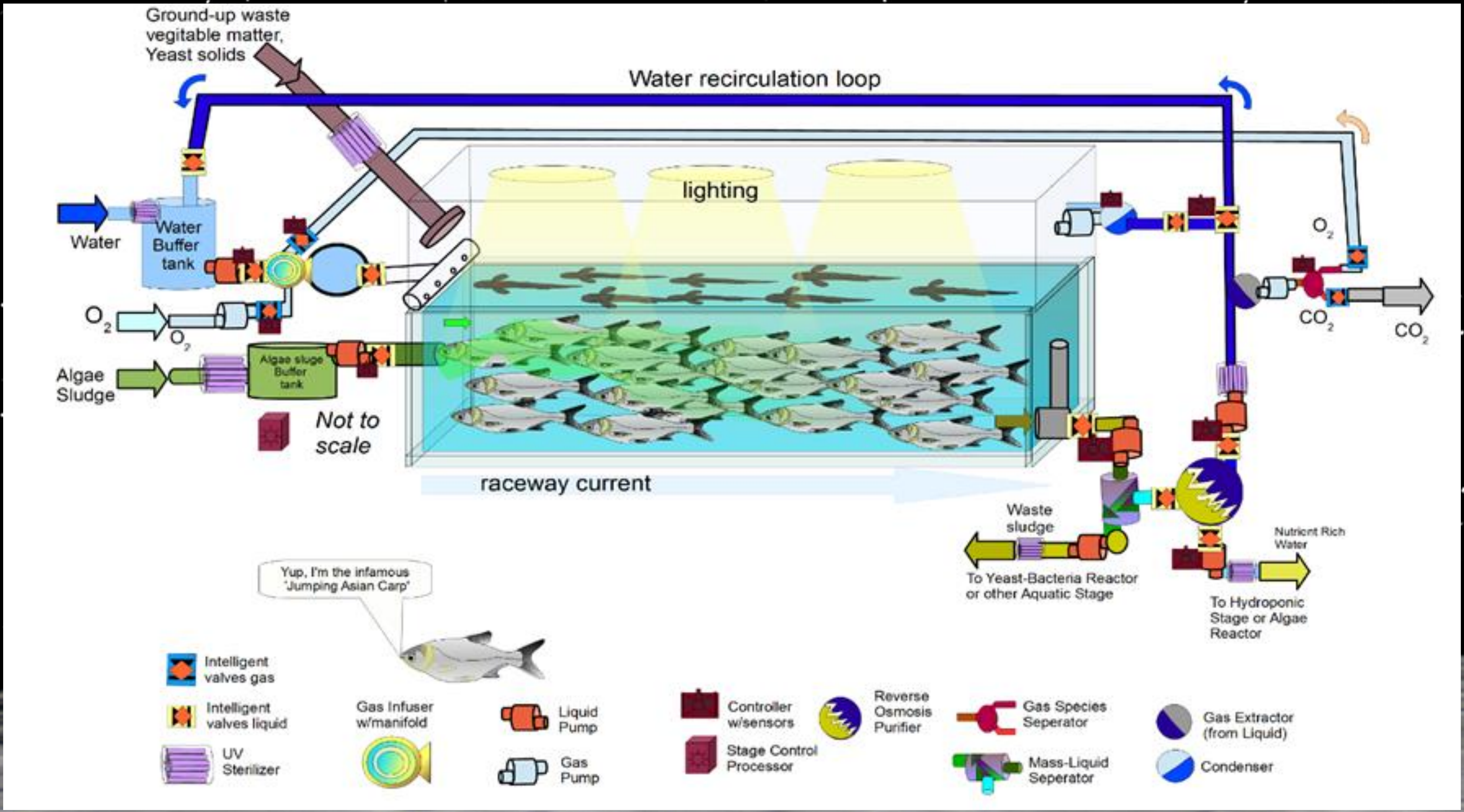
Algae (Photobio-)Reactor Stages

- May use a variety of shapes and either confine the algae to membranes, or in open tubes, etc.



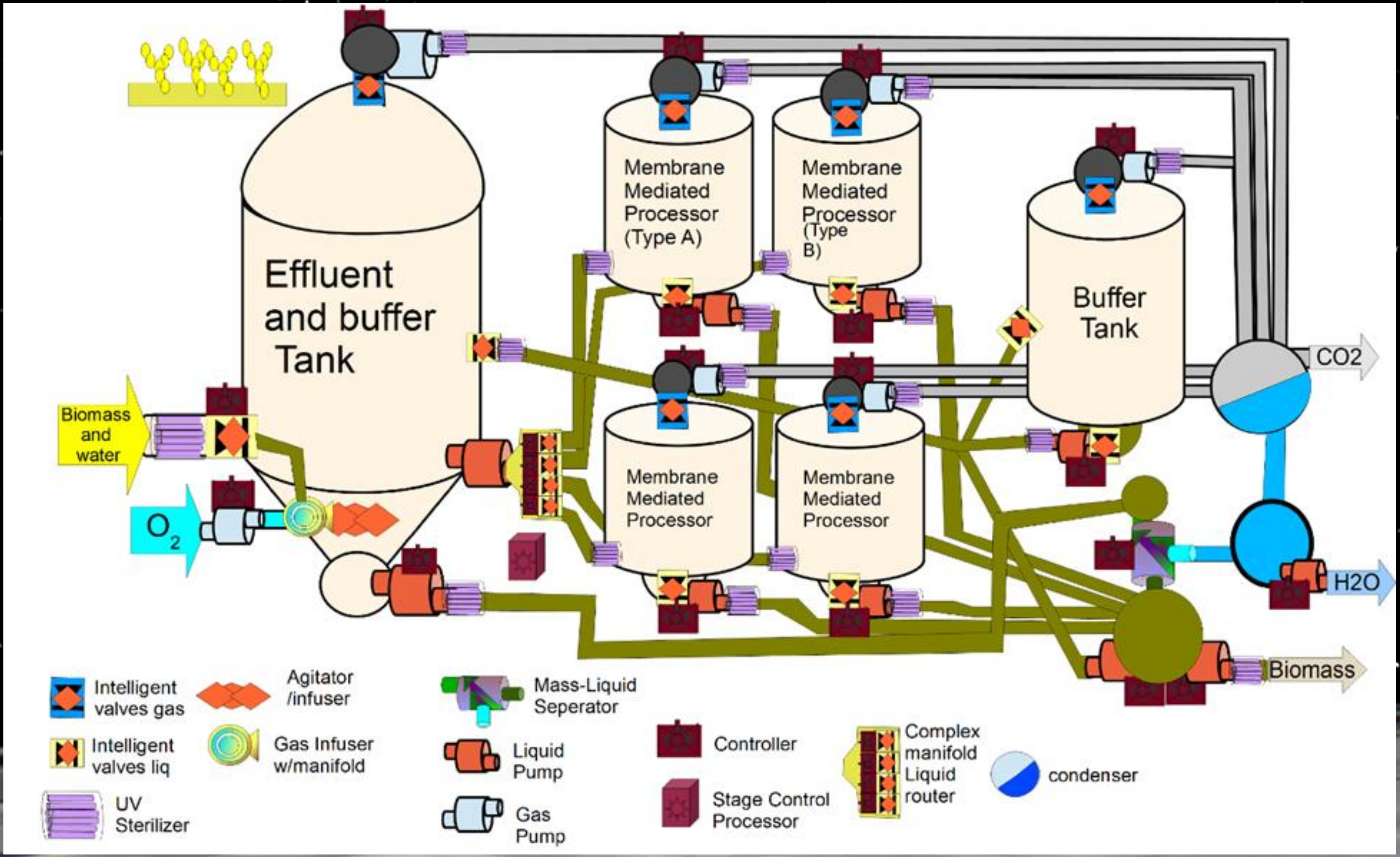
Aquatic Stages

- May use a variety of tank shapes, and may even include plants
- Assume humans or robots feed, tend, and harvest animals

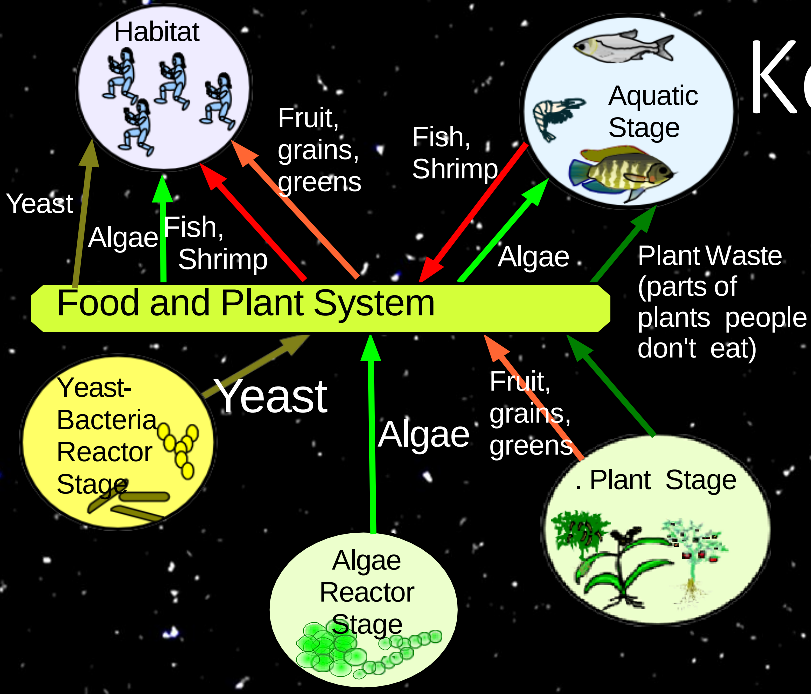


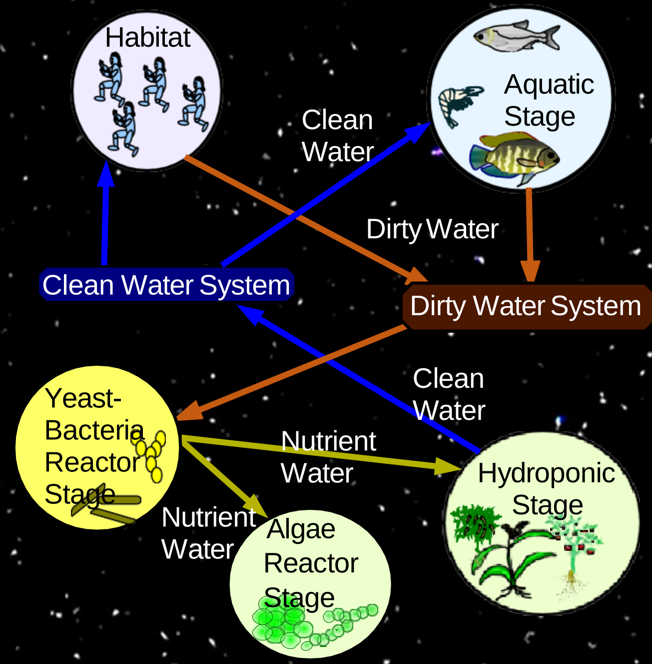
Yeast-Bacteria Bioreactor Stages

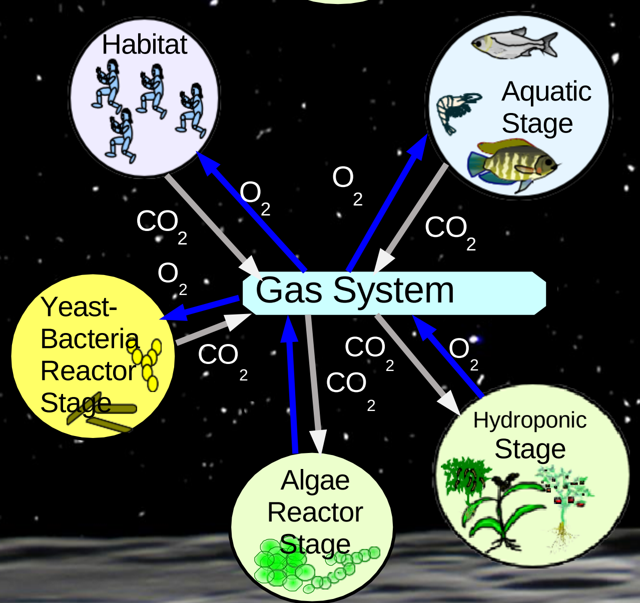
- Complex machines including pumps, tanks, thermal management, and separators
- May produce yeast for food in early farms



Key Space Farm Cycles







Humans: Food+ Oxygen + Water → Water + Wastes (w/Cellulose)+CO2

Animals: (Plant Wastes + Algae + other Wastes) +Oxygen → Water + CO2 + Wastes (w/Cellulose)

Plants and Algae: Energy + CO2 + H2O + Nutrients → Cellulose and Foods

Human + Other Animal Wastes + Plant Wastes +Energy + Water + O2 → Nutrients + CO2 + Water

Key Findings to Date

- Research used models (Genetic Algorithm with Monte-Carlo methods to find mass efficient farm sizes, and calculations using common equipment to find energy)
- Humans do not exhale enough CO2 to feed themselves, so the Yeast-Bacteria Bioreactor and Aquatic Stage must produce CO2 for plants and algae.
  - Almost all the CO2 is from the Yeast-Bacteria Bioreactor in Aerobic Mode, using excess O2 from plants, digesting cellulose, producing some water as well.
- Nutrition balancing and farm size drive at least one animal species.
- Most of the energy in the farm is used to move and circulate liquids.
- More Species = More size and more energy.

Scenarios Used to Date

- Used six scenarios
  - 1A and 1B are very early settlements
  - Scenarios 2A and 2B are next stage settlements
  - Scenario 3 is a fully developed settlement
  - Scenario 4 is a food factory that takes in mass to sell food to other locations.

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

Spice Assumptions

- Assume spices can be grown in the habitat using gray water to add scent and greenery, and to enhance food.
- Some spices take longer then others to grow.

Spice	Scenario					Time to First Harvest (wiki)
	1A	1B	2A	2B	3+4	
Basil	X	X	X	X	X	75 days
Cillantro	X	X	X	X	X	30 days
Dill	X	X	X	X	X	90 days
Fennel	X	X	X	X	X	100 days
Mustard	X	X	X	X	X	95 days
Chives	X	X	X	X	X	60 days
Marigold (Candula)	X	X	X	X	X	70 days
Mint	X	X	X	X	X	90 days
Taragon	X	X	X	X	X	60 days
Oregano		X	X	X	X	120 days
Cumin		X	X	X	X	120 days
Ginger		X	X	X	X	200 days
Serrano Peppers*			X	X	X	120 days
Paprika*			X	X	X	150 days
Saffron			X	X	X	180 days
Chili Peppers*			X	X	X	120 days
Corriander			X	X	X	100 days
Garlic			X	X	X	180 days
Tumeric				X	X	300 days
Thyme					X	1 year
Rosemary					X	1 year
Hops					X	2-3 Years
Coffee**					X	2-3 Years
Tea**					X	2-3 Years
* = Same species as bell peppers						
** = large enough to require space and possibly a hydroponic stage, good for export!						

Scenario 1A Menu Options

- Initial Settlement, 0 to 1 level. Will import many spices and likely special foods to enhance diet.
- Can make yeast and algae bars, cakes, protein drinks (ugh).
- Ferment algae using yeasts to make algae wine/kombucha.
  - 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.
- Could use chemistry to extract sugars, proteins to make other processed foods. Algae jelly (agar) can be used to make 3d printed shapes, waffles, gummies.

Scenario 1B Menu Options

- Same level as 1A, with more time, and tomatoes
- Tomato Salads flavored with dried yeast and algae powders
- Ferment tomatoes to get wine and vinegar
  - Vinegar opens up many recipe options.
  - Vinegar from tomatoes, and oils from algae can be used to make salad dressings and dips.
  - Wine would be very like a veggie drink or Bloody Mary.
- Make noodles from algae and yeast powers.
  - Could make many noodle and noodle bowl dishes.
- Sauces: Given spices, a marinara could be made. Make 'meatballs' from yeast.

Scenario 2A Menu Options

- Settlement is a developing sustained settlement (Level 1) with few imports.
- 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 Menu 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, for beer
- 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 (e.g. panko).

Scenario 3+4 Menu Options

- Steady State Settlement (Settlement Level 2 to 3), and may contribute (Scenario 4) to a trade web.
- All previous options plus:
- Barley makes soups, flour, and real beer.
  - Sprouting barley makes malt for beers and other drinks (malted soymilk shakes?), and bulk enzymes to make sweeteners from starches.
- Soybeans add tofu, edamame, soy sauce, sprouts.
  - Fermenting soybeans = soy sauce.
  - Soybeans are an easy source of oils, and powders.
- Fried fish, shrimp, doughnuts, French fries, etc. using soy oil.
- Assuming this settlement has had a few years:
  - Possibly Coffee and Tea, good 'boutique' export.

Future Work

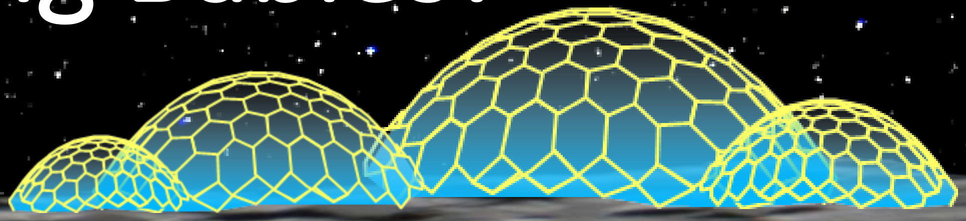
- Paper at AIAA SPACE 2018 covers energy use.
- Enhanced collaboration
- Expansion of experiments in bioreactors and hydroponic growth.
- Refinement of models using better data
- Scale closed cycle farms.
- Design of key machinery.

Thank You for Coming!

And remember:

Why do we settle space?

Trillions of Happy, Smiling Babies!



BACKUP

Basics: Farm as Chemical Plant

- Each Stage is essentially a biochemical factory
  - Many components are required to link stages together and to the habitat!
  - Examples: Pumps, tanks, separators, control systems, etc.
- Core Cycles:
  - 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
- Four Stage types (in my models):
  - Photobioreactors/Algae Stage: High surface area growth machines for algae and water plants
  - 'Hydroponic' Stage: Vascular Plant Growth: Hydroponic/Aeroponic/Aquaponic growth chambers and machines for high speed plant growth
  - Yeast/Bacteria Bioreactors: High surface area aerobic and anaerobic bioreactors. Includes Septic Tanks.
  - Aquatic Stage: Growth of Aerobic Animals in tanks and raceways. Examples: Shrimp, Fish.
- As settlements mature:
  - Animal Stages: Animals grown in atmosphere, ex: Chickens
  - Soil-based Fields: Plants grown in living soil (as in a field on Earth)

Short Description

- **Space Farming, Menus, and Biological Life Support: For Here and There**
- In space, whether in zero gravity like the ISS, or in gravity, as in rotating stations or on the Moon or Mars, room is tight and mass is expensive! What technologies will make growing food in space possible? How do we tie various machines and organisms together to feed people and recycle air and water? How do we make farms that can provide food to other settlements and maybe even back to Earth? What kinds of meals can future space tourists, workers, or settlers expect?