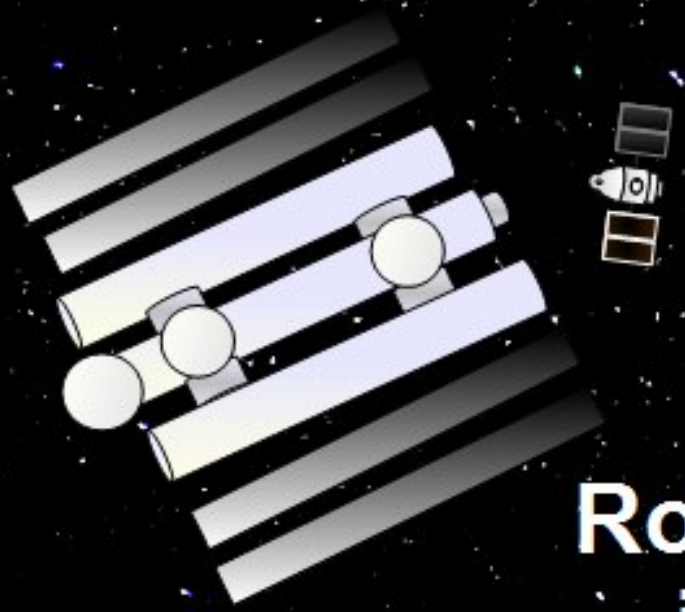
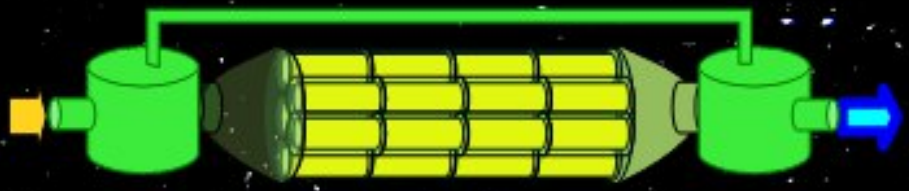
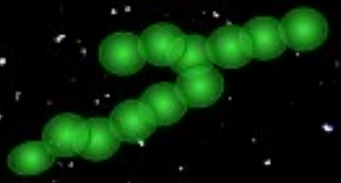






Role of Bioreactors in Space Farms

Bryce L. Meyer

Gateway to Space 2016, St. Louis MO, 8 Oct 2016

Overview

- Work to date has included simulations for mass balance using data from various sources. Papers in AIAA conferences, and informal sources.
- Focus Here:
  - Space Farms 101
  - Pseudo Ecosystem Dynamics
  - Space Farm Stage Elements inlcuding Bioreactors
  - Bioreactor Notes and Dynamics
  - Further Work

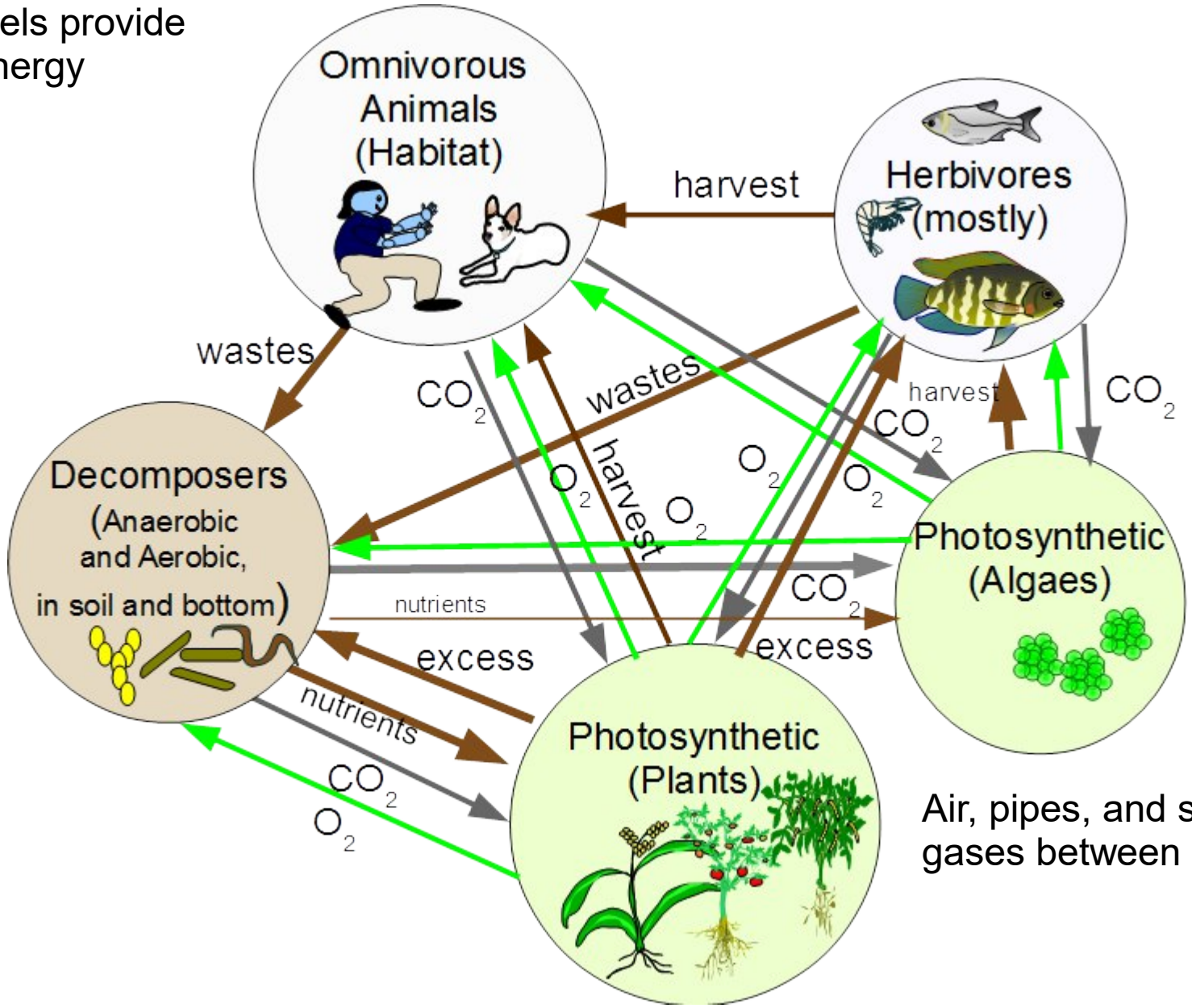
Space Farm 101

- The Closer a Space Farm and Habitat together emulate an ecosystem, the more efficient it will be.
- Four Stage Types in this farm concept:
  - Hydroponic: Grains, Legumes, Vegitables, Fruits
  - Aquatic: Fish, Shrimp, Molluscs, other Crustaceans
  - Yeast-Bacteria Reactor: Film and Tank Bioreactor
  - Algae Reactor: High efficiency algae growth reactor

Driving Question: What combinations of species, meet the nutritional needs of the habitat, AND recycle gasses and water for mass balance, especially Nitrogen balance?

An Earth Farm Example Pseudo Ecosystem

Sun and fuels provide energy

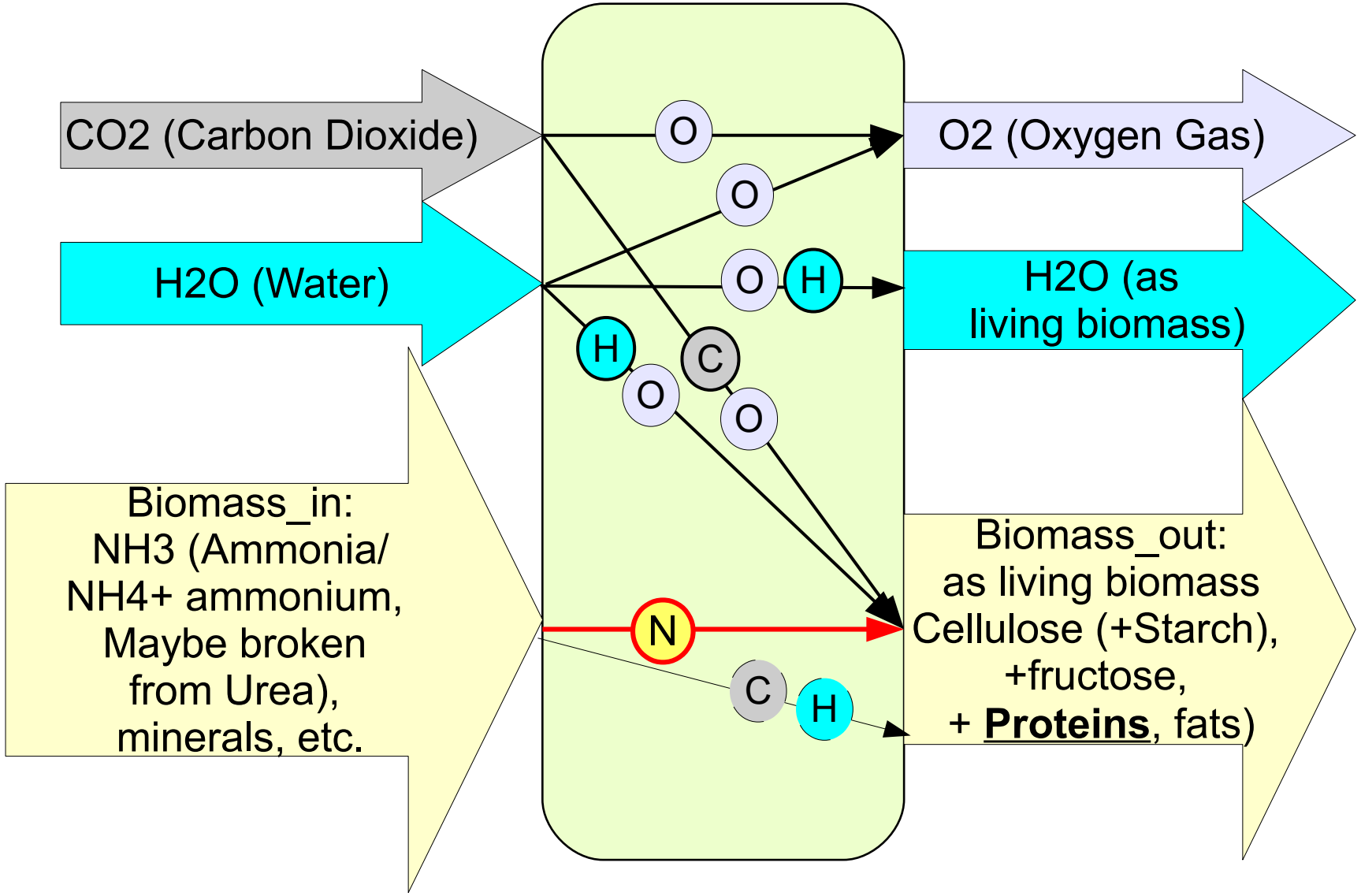


KEY

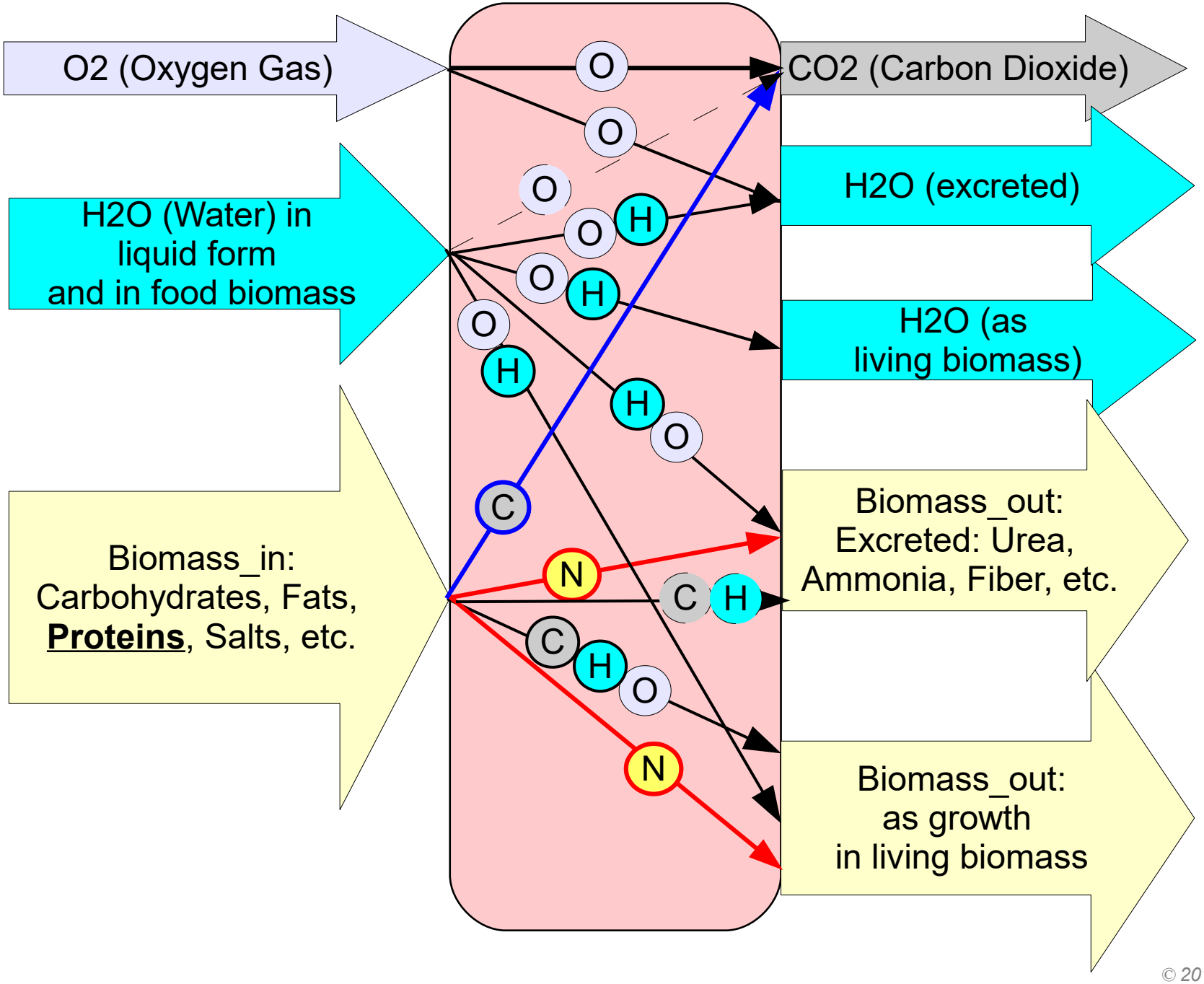
- Biomass
- Oxygen
- Carbon Dioxide

Air, pipes, and soil cycle water and gases between organisms

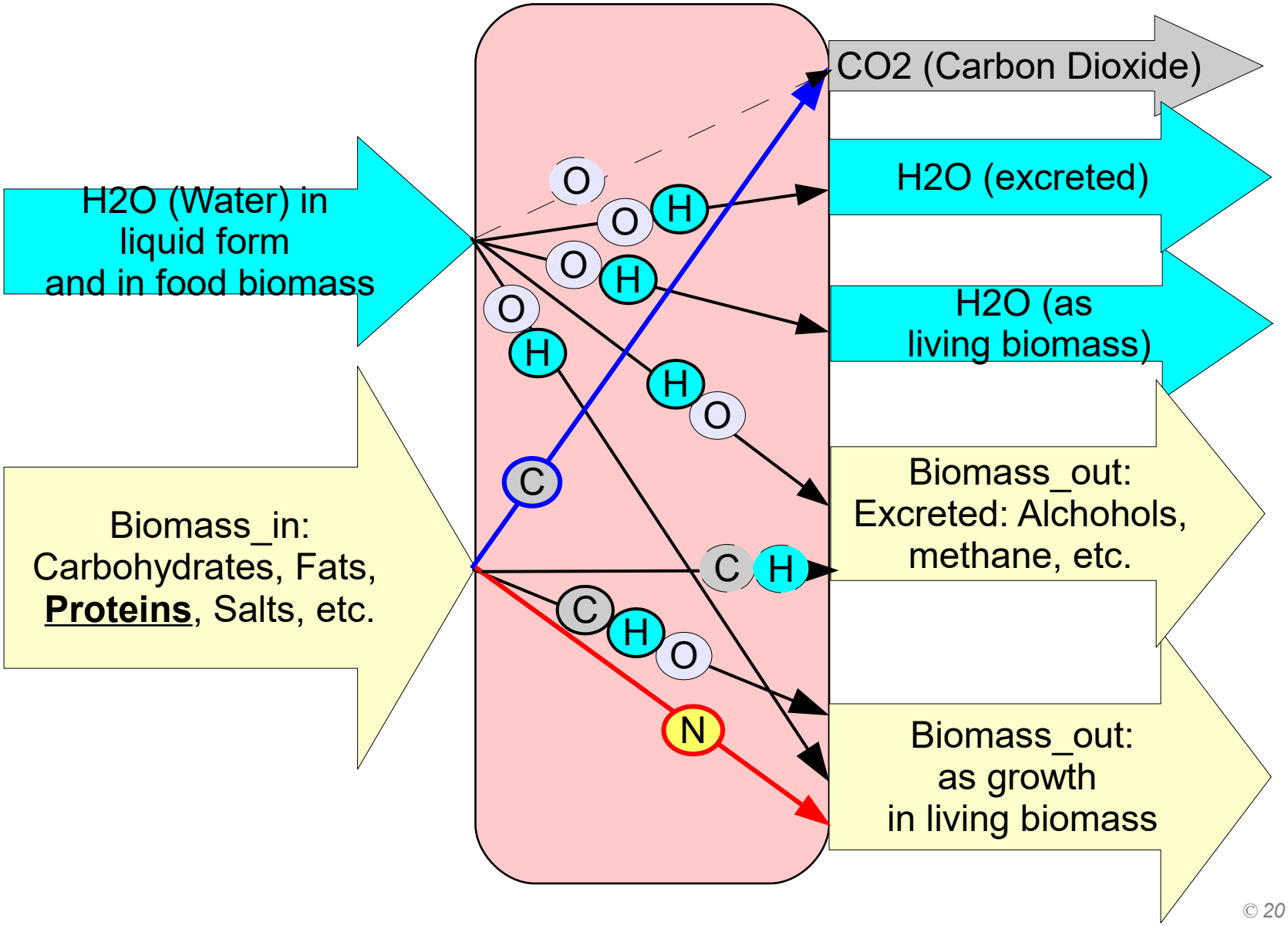
Mass Balance in Photosynthetic Organisms (i.e. Algae and Hydroponics)



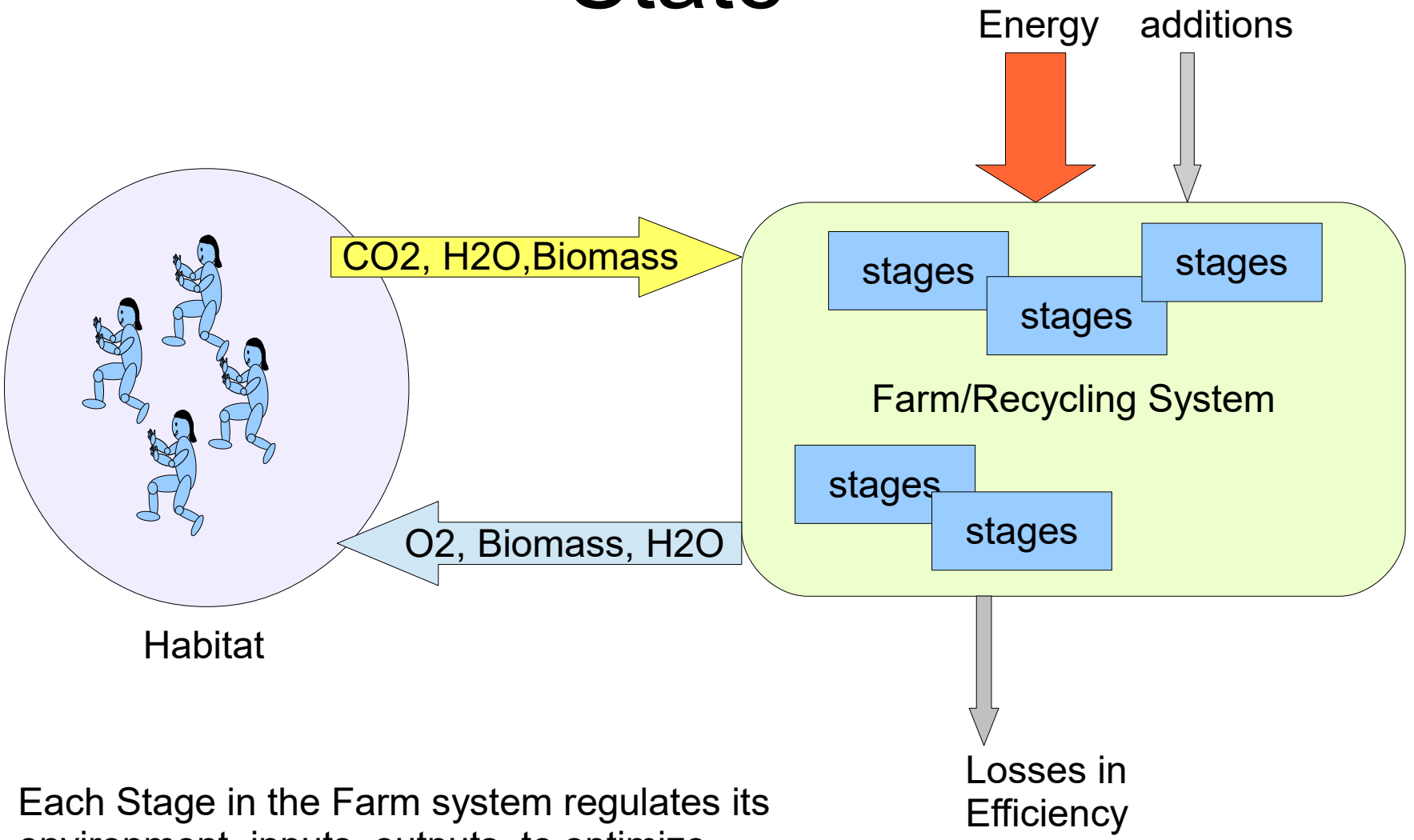
Mass Balance in Aerobic Organisms
(i.e. Yeast-Bacteria Reactor in Aerobic Mode, and Aquatics)



Mass Balance in Anerobic Metabolism (i.e. Yeast-Bacteria Reactor in Anerobic Mode)

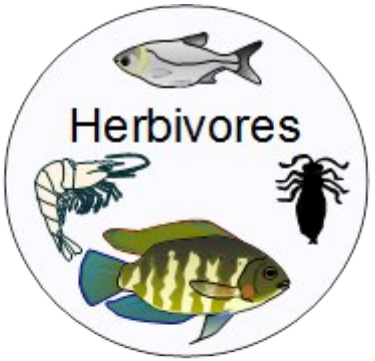


Overall System Balance at Steady State



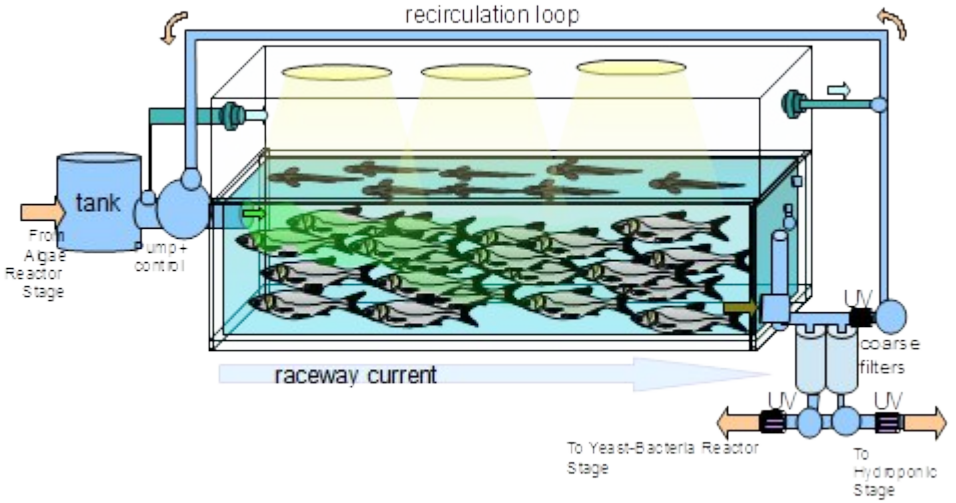
Each Stage in the Farm system regulates its environment, inputs, outputs, to optimize growth.

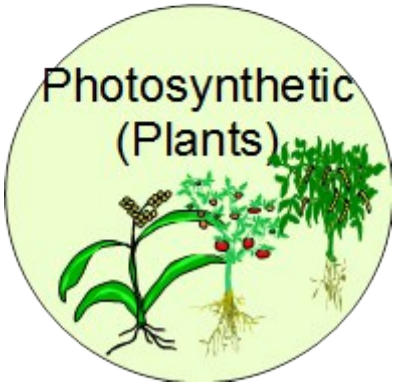
Replicating the Ecosystem: Plants and Animals Stage Types



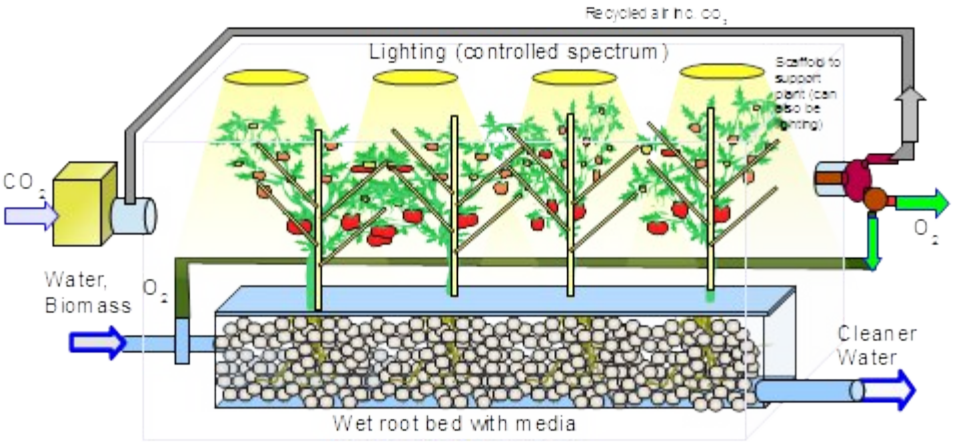
High Density Raceways or Tanks w/auto-feeders, macerated output from hydroponic components and from Algae Reactor. Yeast-Bacterial reactor my provide additonal feed in some scenarios. Liquid excretes (urea, ammonia) go to Algae Reactor and Hydroponic beds. Solids go to the Yeast-Bacteria reactor. Crop inedibles to Yeast-Bacteria after sterilization and maceration.

Aquatic or Terrarium

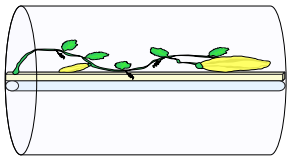




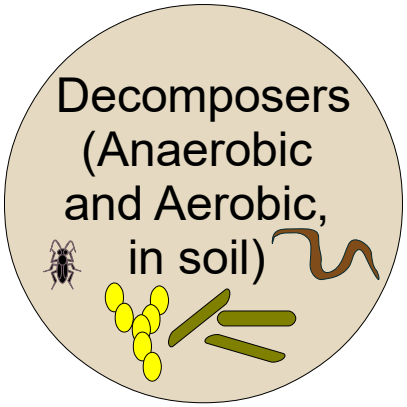
High Density Hydroponics with dispersed light sources (above and on scaffolding)
Inert biomedia seeded with bacteria. Grain crops will be complete harvest, fruit/vegitable crops have trimming and fruit produce, long life species. Tree grafts can be used in lieu of whole trees to produce fruit.
Excreted sterilized wastes (urea, ammonia) as needed from habitat and aquatic stages.
In habitat grey-water hydroponic production of spices and vine crops.



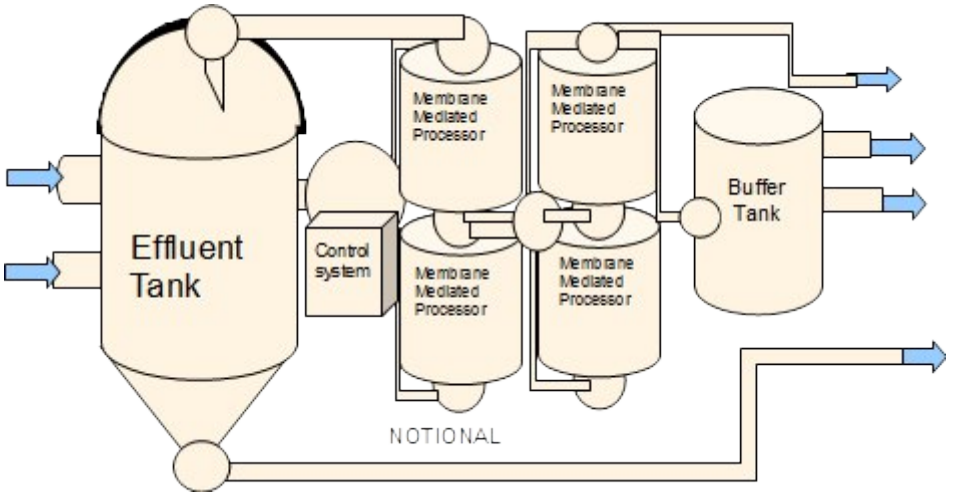
High Efficiency Hydroponic

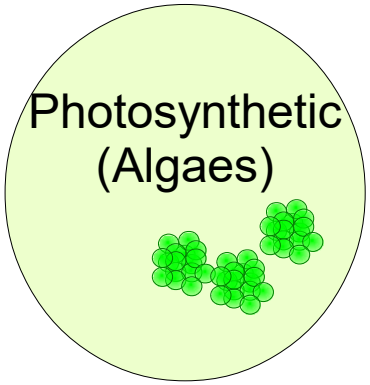


Replicating the Ecosystem: **Bioreactor Stages**



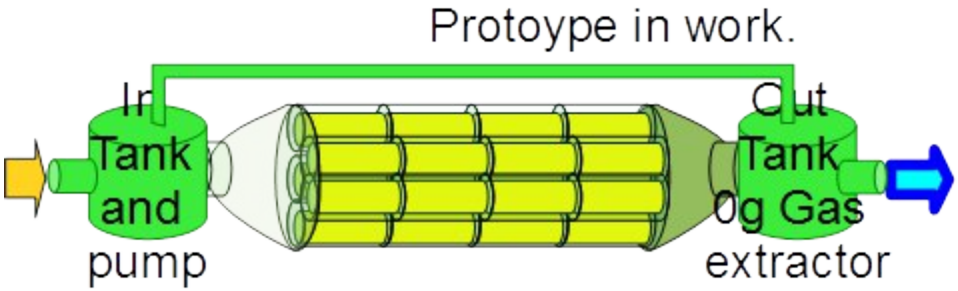
A multipurpose mass balancer. Usually in Aerobic modes to produce CO_2, but can produce biomass. Decomposes inedible produce (Cellulose, etc.) and other wastes. High surface area confined bacteria and yeasts. Cycling to components depends on desired outputs. Complex control systems. Simplified assembly using rolled flat surfaces.

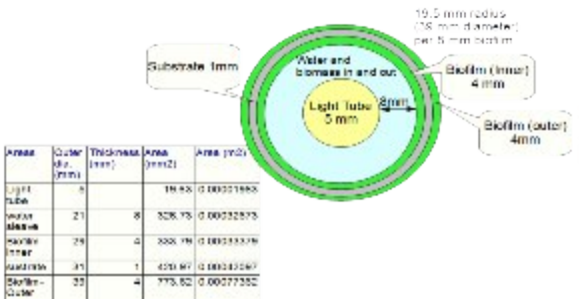




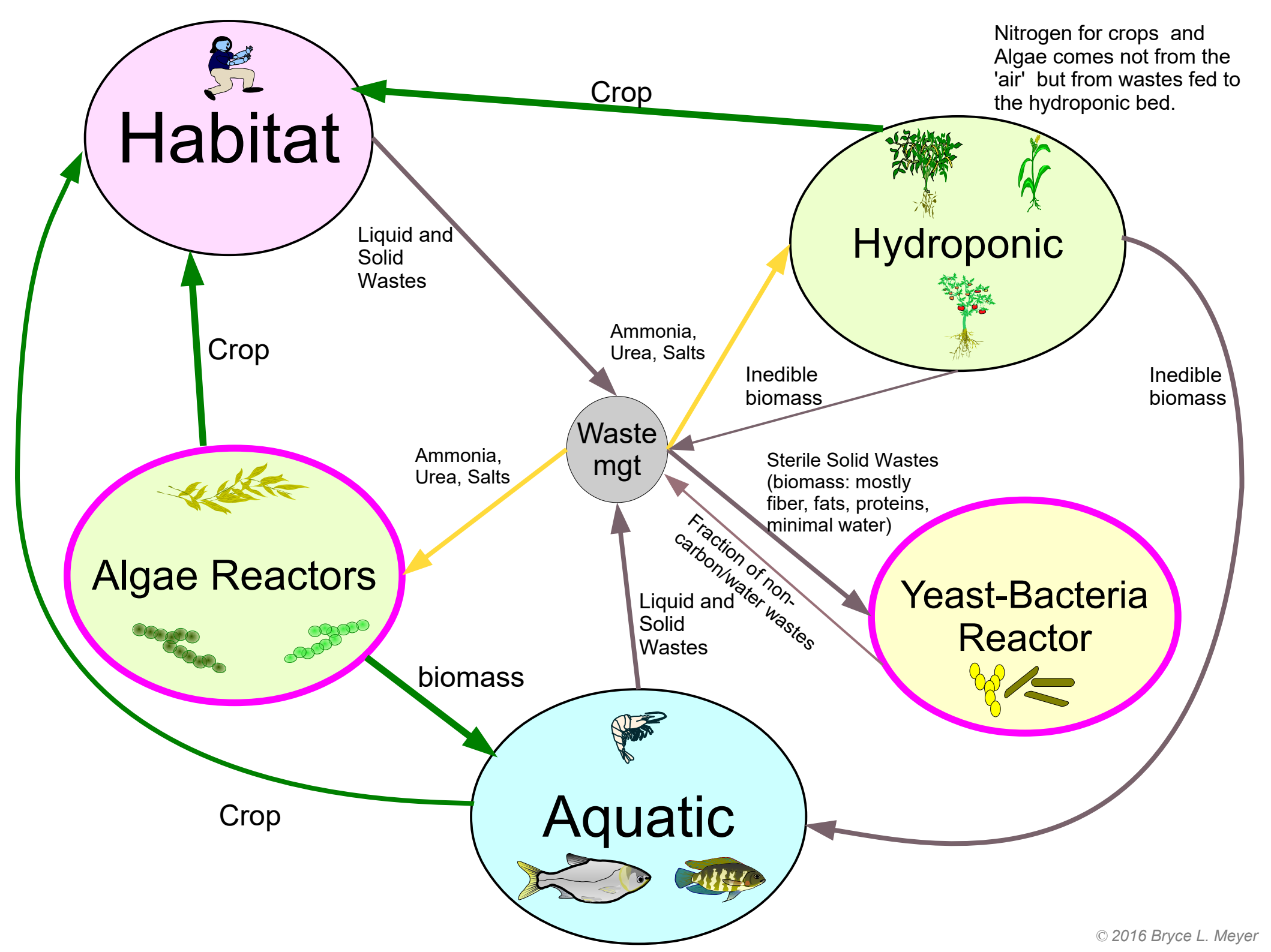
Spriulina or Chlorophyta

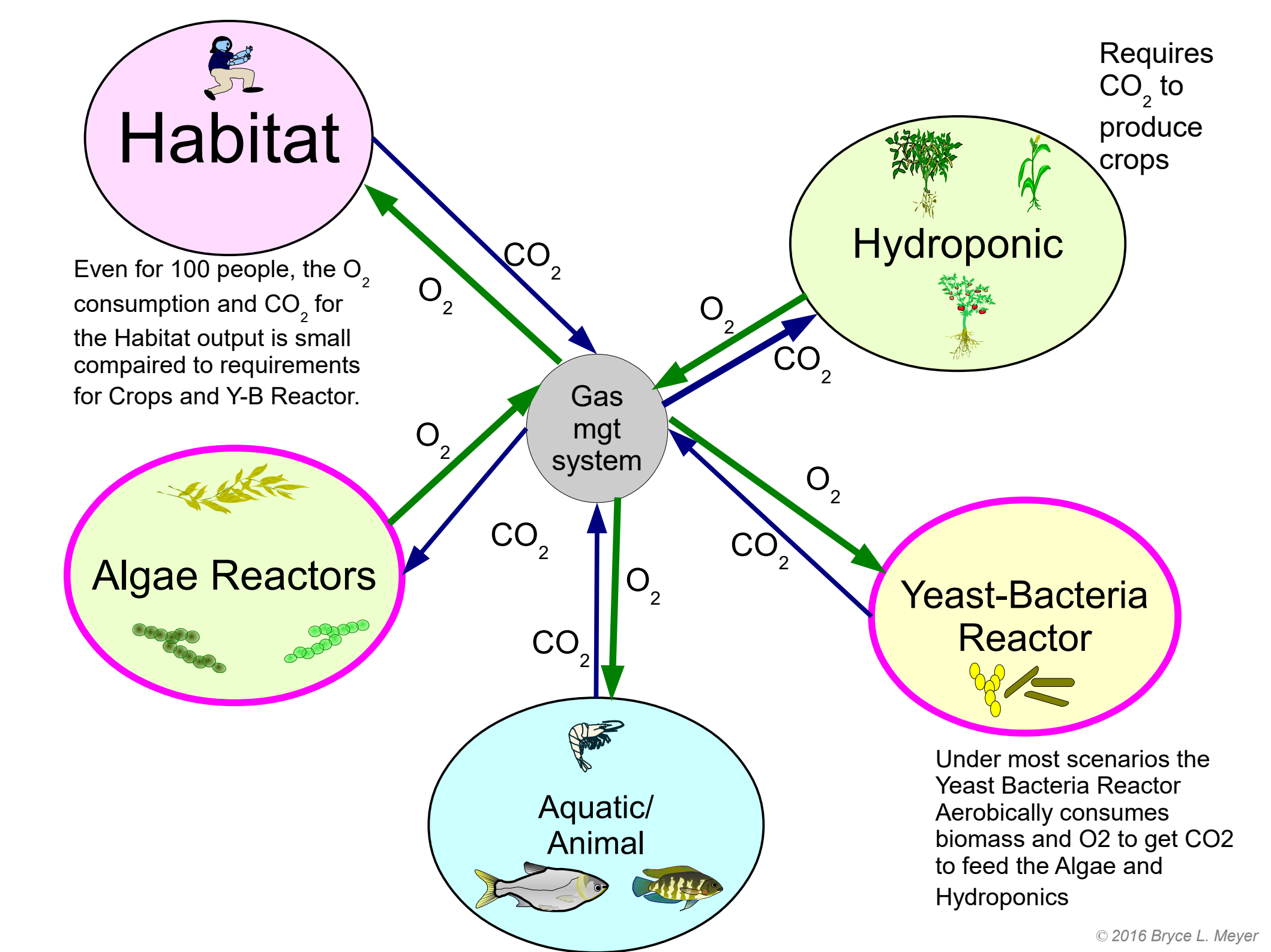
Primary Oxygen producer and Ammonia recycler. Produces the primary feed for Herbivores. High surface area exposure to tuned LED light tubes in proximity to mesh or membrane confined colonies. Gas extraction and pulsed pumps are keys to balancing CO2 and biomass production.



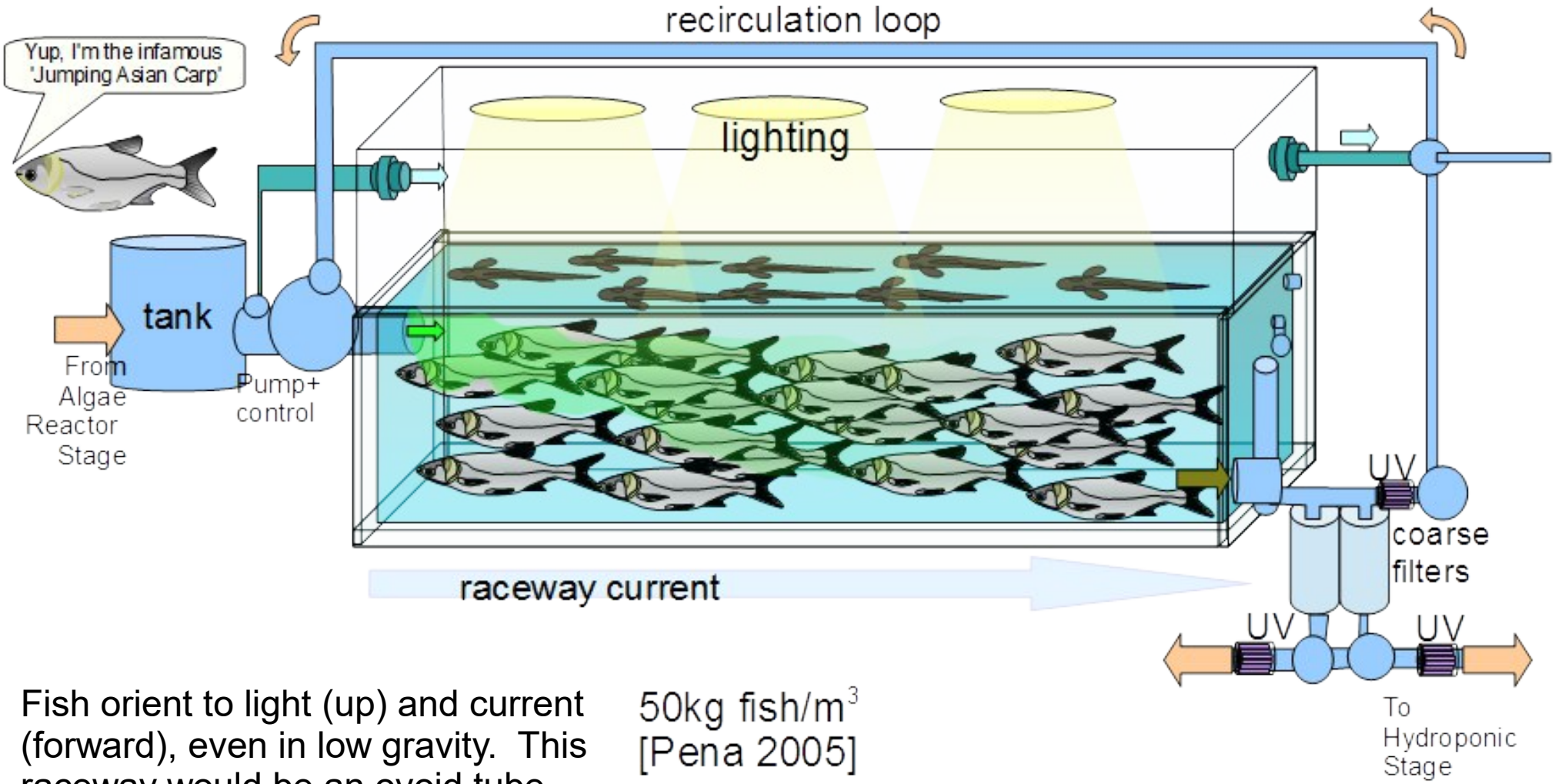


Early notional design. New design (not shown) uses meshes in a simpler form for better CO2 exposure.





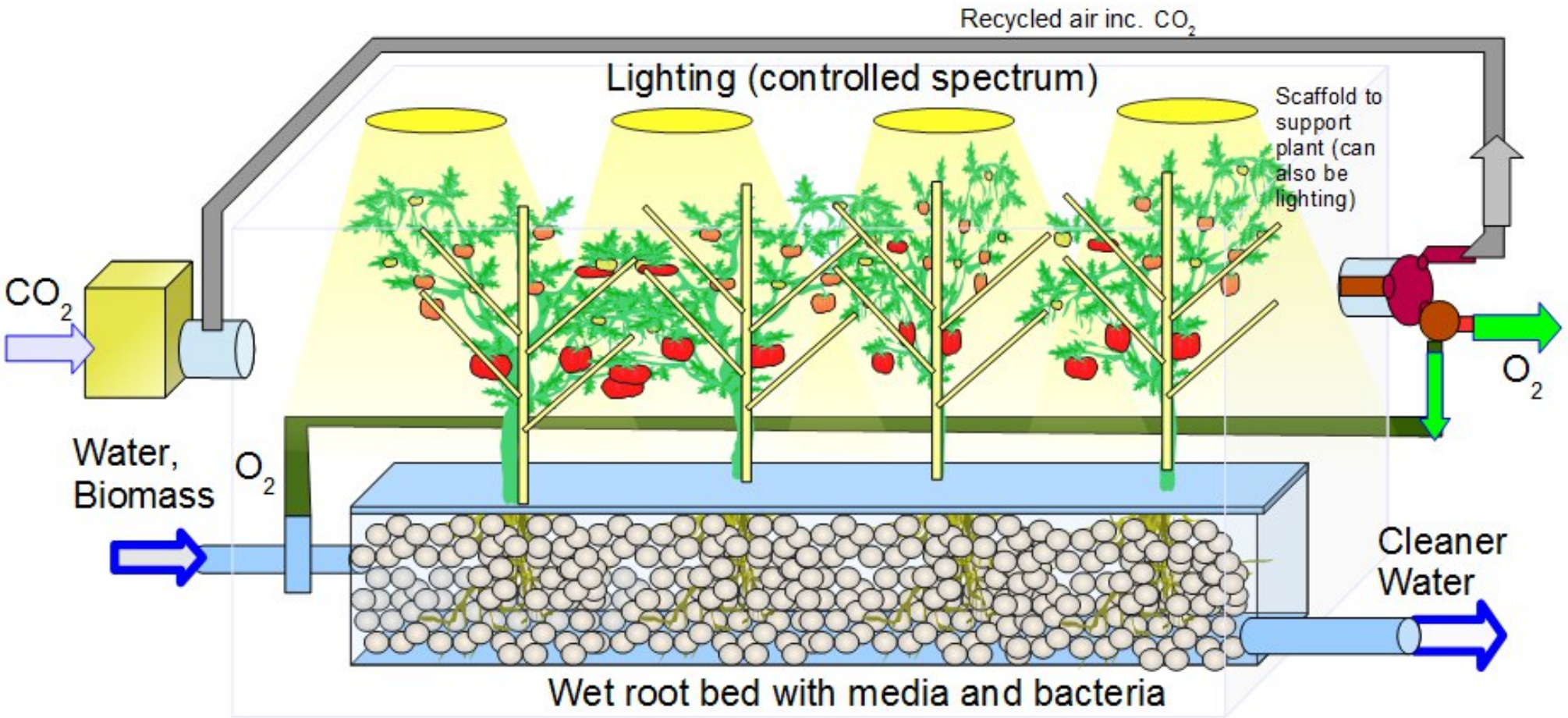
Aquatic Stage Basics



Fish orient to light (up) and current (forward), even in low gravity. This raceway would be an ovoid tube with air infusers in 0 g.
Multiple raceways for juvenilles and Breeders

50kg fish/m^3
[Pena 2005]

Hydroponic Stage Basics

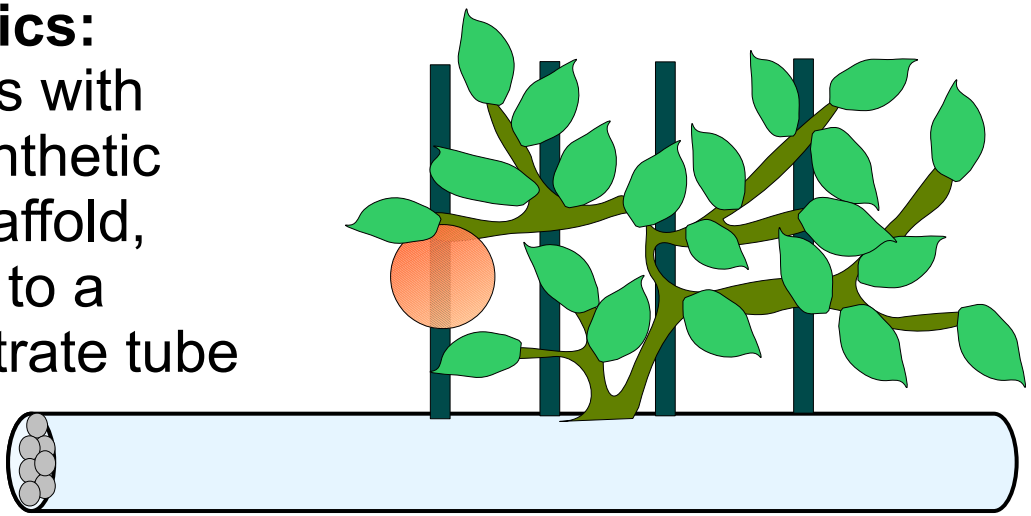


Lighting is distrbuted, not just overhead, via light tubes and light shapes.

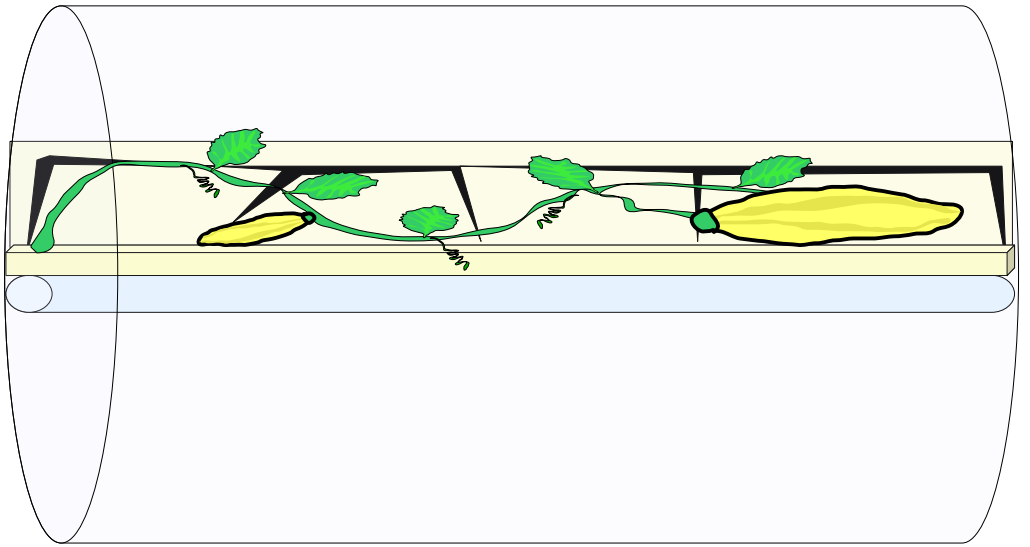
Atmosphere is carbon dioxide heavy, tending by humans in masks or robots.

Graft Hydroponics and Vine Hydroponics

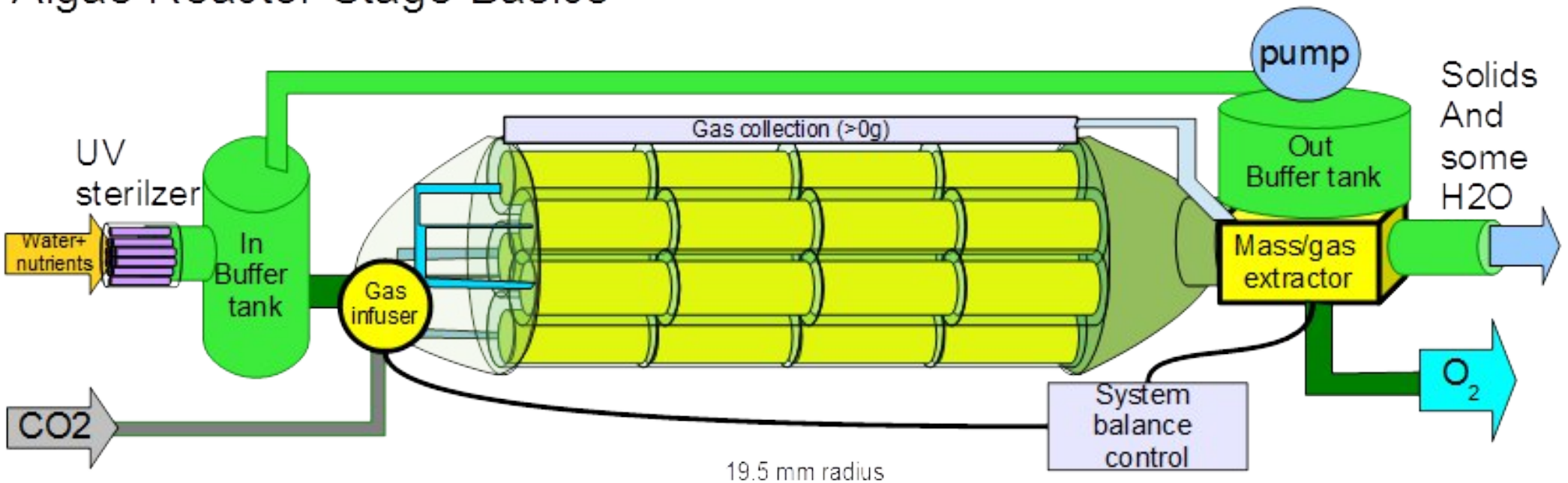
Graft Hydroponics:
Fruiting Branches with minimal photosynthetic leaves, and a scaffold, directly attached to a hydroponic substrate tube

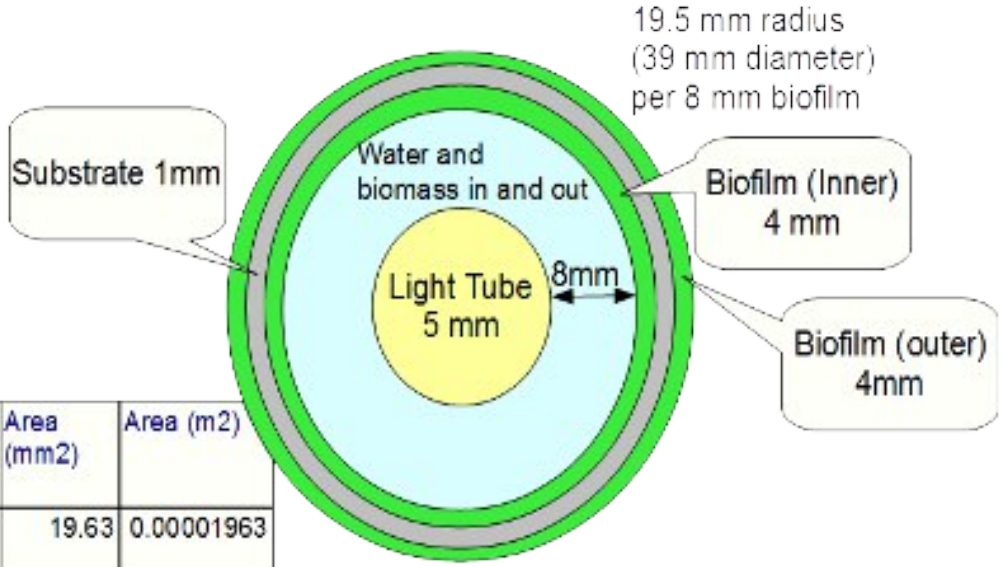


Vine Hydroponics:
Vines in Habitat with scaffold and light wall, hydroponic substrate tube is part of the gray water recycling system.



Algae Reactor Stage Basics



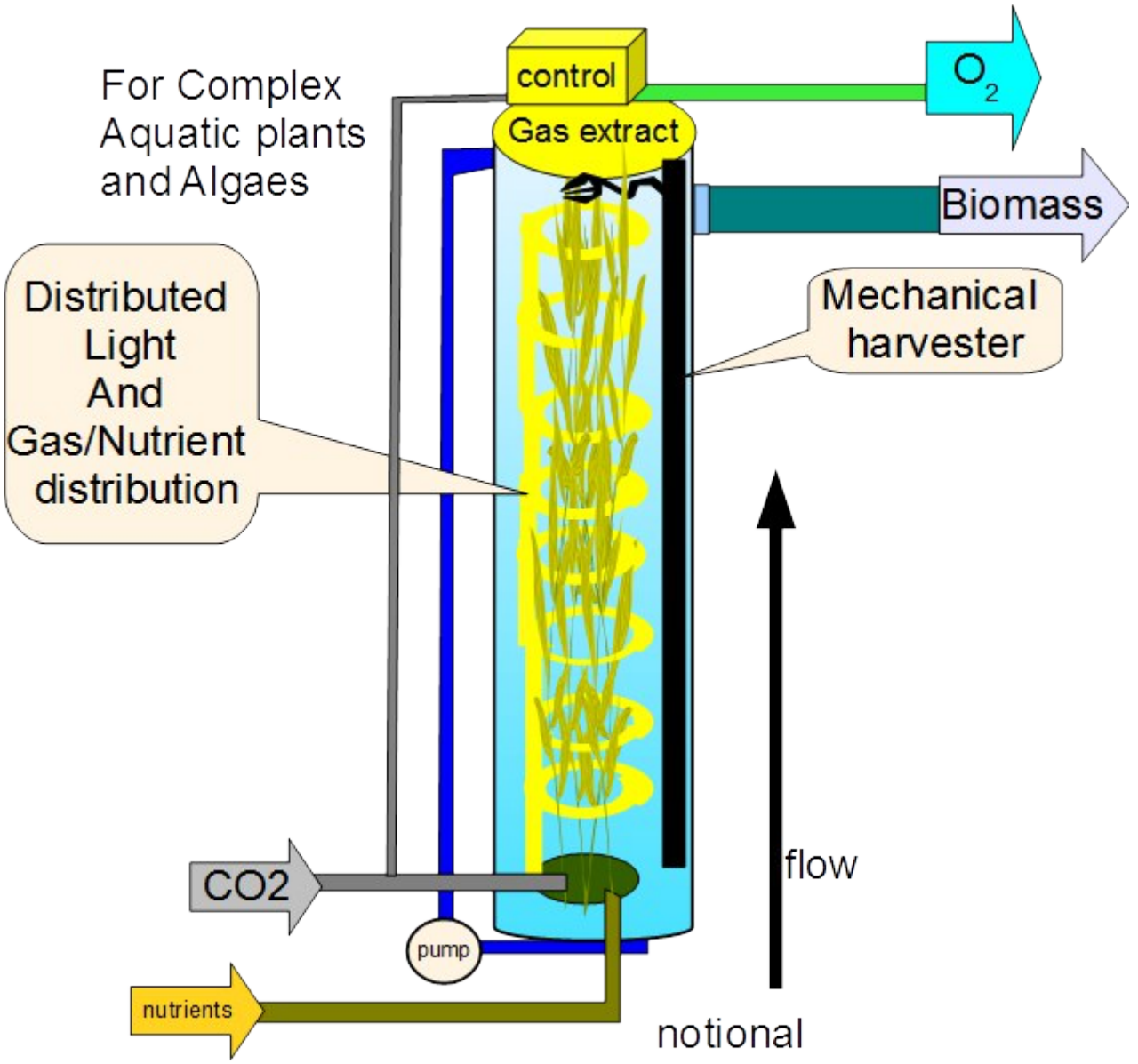


Areas	Outer dia. (mm)	Thickness (mm)	Area (mm2)	Area (m2)
Light tube	5		19.63	0.00001963
water sleave	21	8	326.73	0.00032673
Biofilm inner	29	4	333.79	0.00033379
sustrate	31	1	420.97	0.00042097
Biofilm-Outer	39	4	773.62	0.00077362

Early Notional Design for sizing..a better design is protoype and pat. pending.

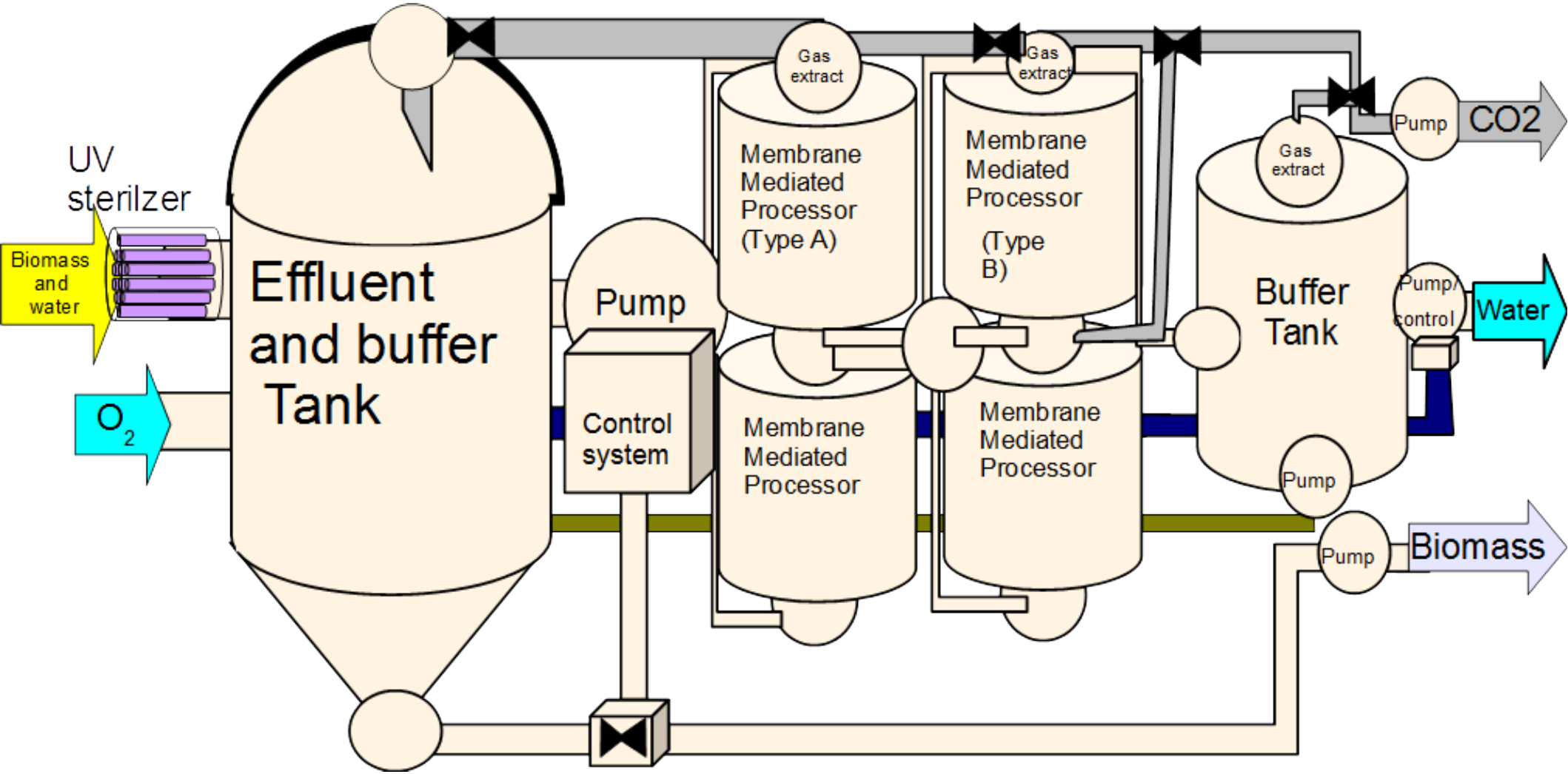
- Challenges include:
  - CO2 to O2 Saturation/starvation in sections.
  - Gas-dissolved gas balance.
  - Clog prevention
- Pulsing Flow will send algae clumps and oxygen into the Aquatic Stage (to be eaten by shrimp or fish), along with unused detritus.
- The reactor maximizes the surface area of algae exposed to nutrients and light.

Sea Weed/Kelp Reactor



Note Well: it would be better to confine cells to a substrate and use the primary Algae Reactor design, but if impossible, this is another option.

Yeast Bacteria Reactor Stage Basics



NOTIONAL

Example Mass Flows, 9 Species

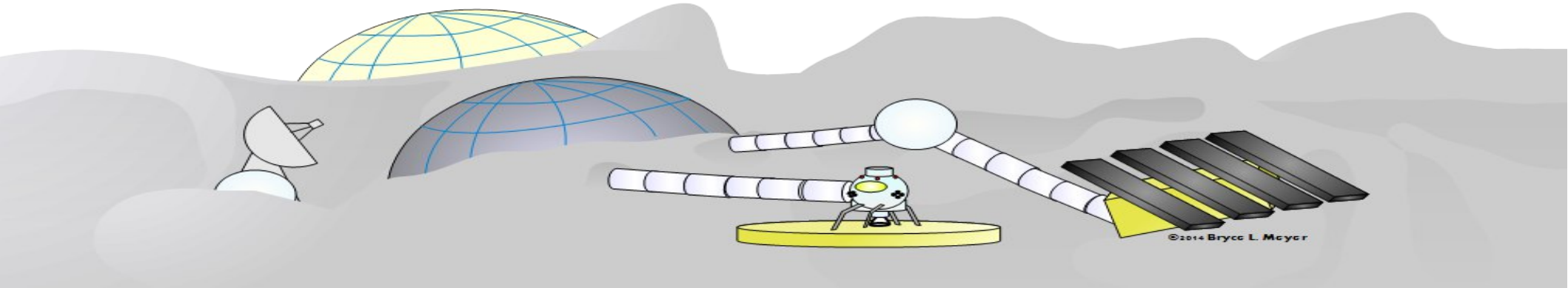
- Using a Monte-Carlo Analysis and a series of near-ideal assumptions, using 9 species, a series of mass flows from AIAA-2016-5586 with updates, 100 colonists, by day:

Algae Reactors	Net In (kg)	Net Out (kg)
Gases	2.83	2.15
Dry Biomass	0.39	1.87
Liquids and water in wet biomass	90.42	89.62
Living Biomass (wet, total) kg	1200	cell mass bound to membranes

Yeast-Bacterial Reactor	Net In (kg)	Net Out (kg)
Gases	913	993
Dry Biomass	470	9
Liquids and water in wet biomass	10	391
Living Biomass (wet, total) kg	2786	includes effuent tank cells and cells bound to membranes

Conclusions and Future work

- Continued Mass Flow Analysis
- Construct Algae Protoypes to collect data and refine design for possible patent.
- Collect and gather data from other hydroponic efforts to refine sizing and in-situ.



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