Multistage Space Farms (Artificial Ecosystems in Space)

International Space Development Conference
Space Settlement Track
27 May 2017

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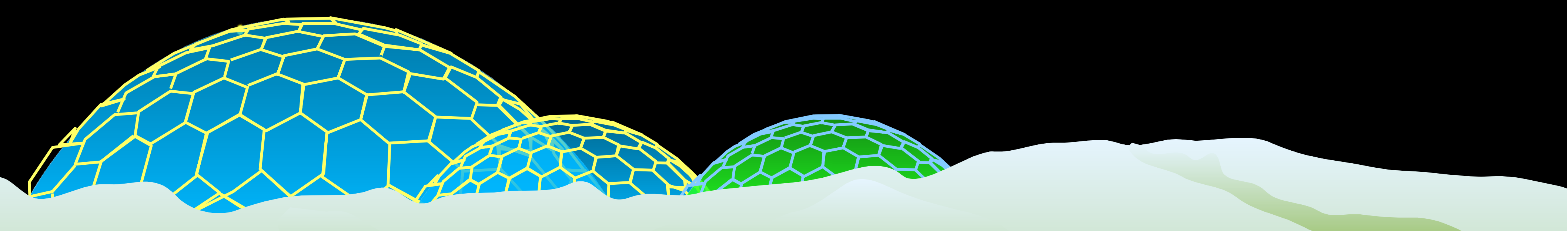
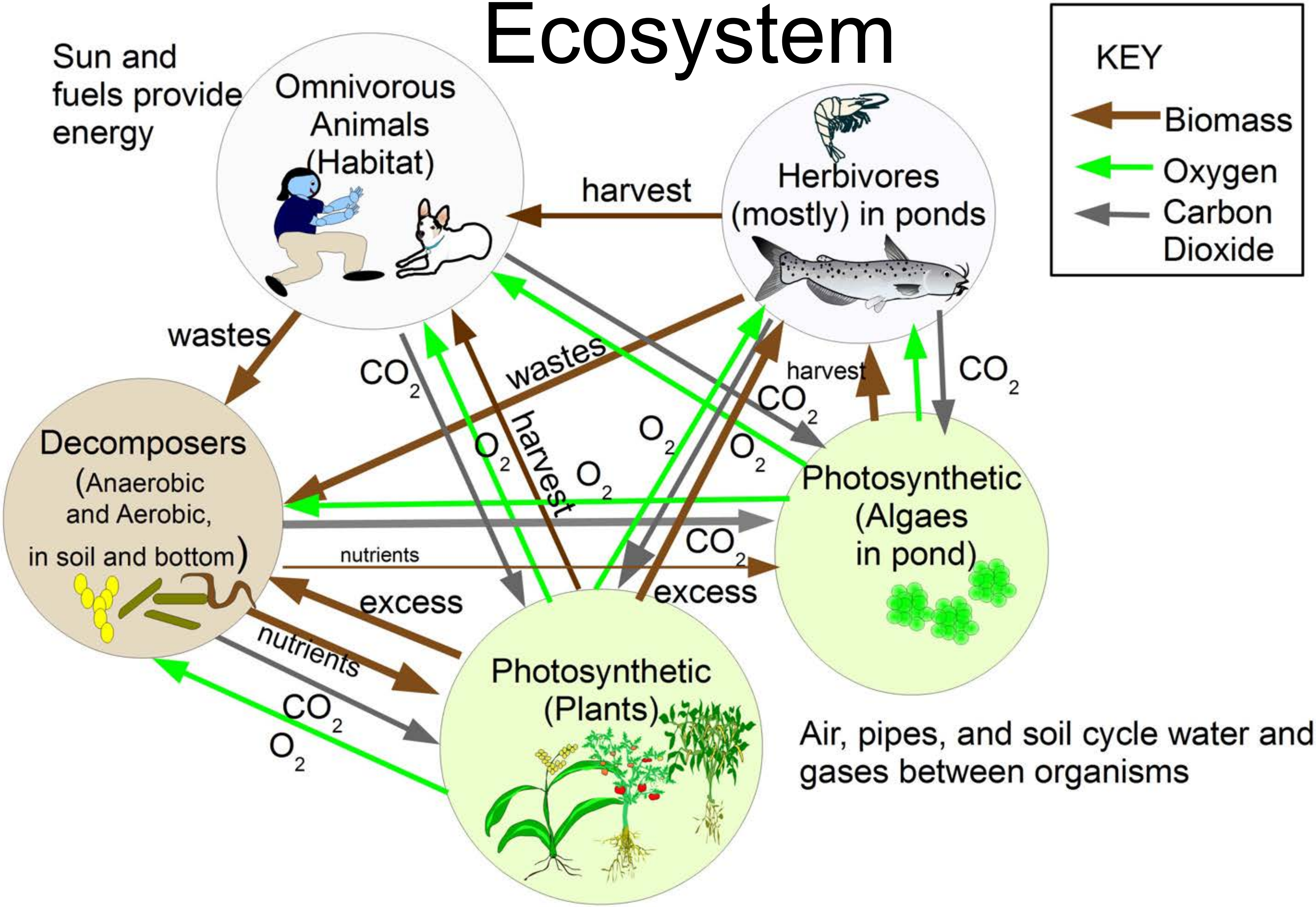


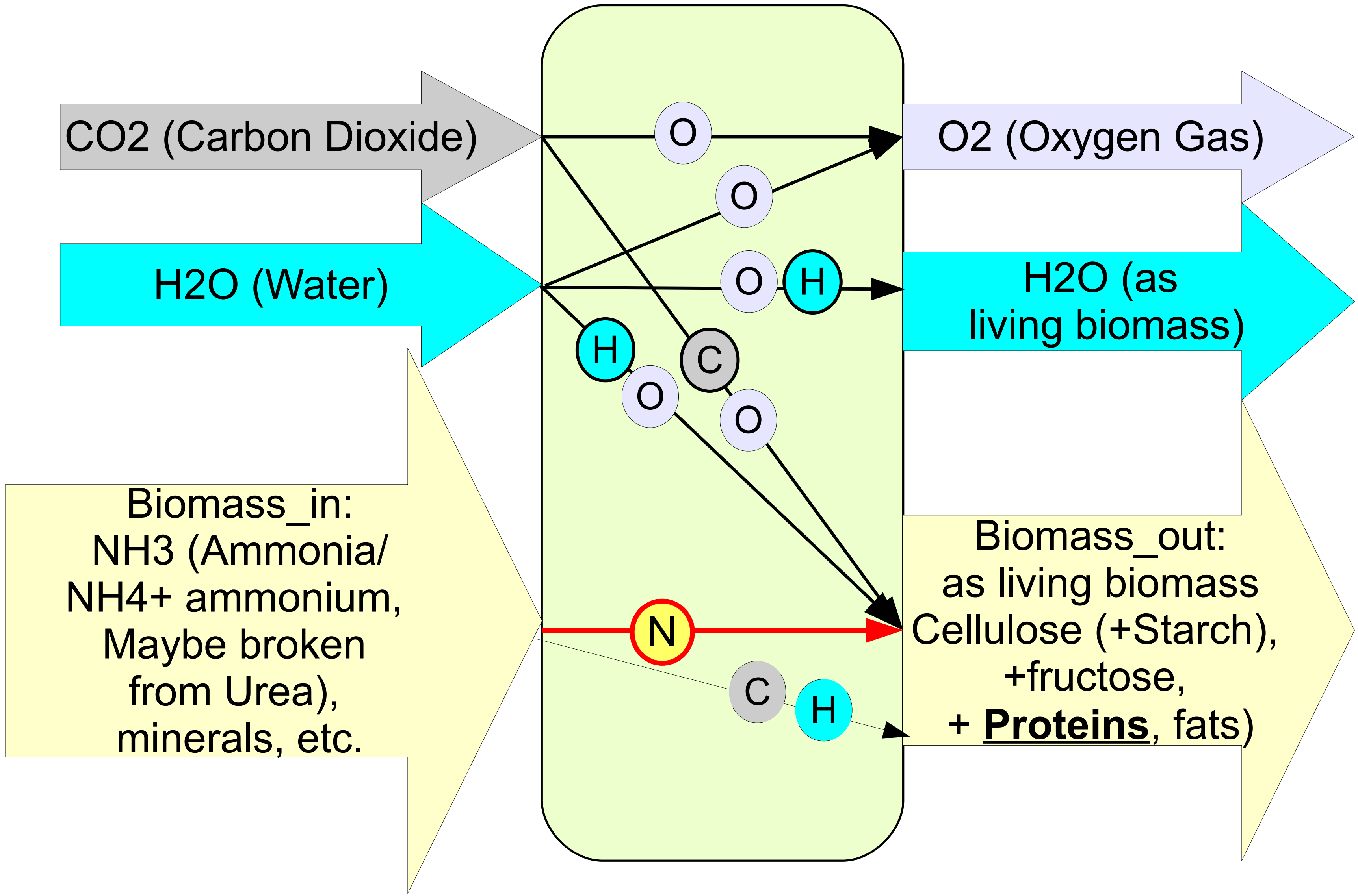
Overview

- What is a (Recycling) Space Farm?
  - Principles
- Stages in this farm
  - Equipment
  - Relationship to Earth ecosystems
- Possible Counts and Results
- Menus and Recipes
- Conclusion/Future Work

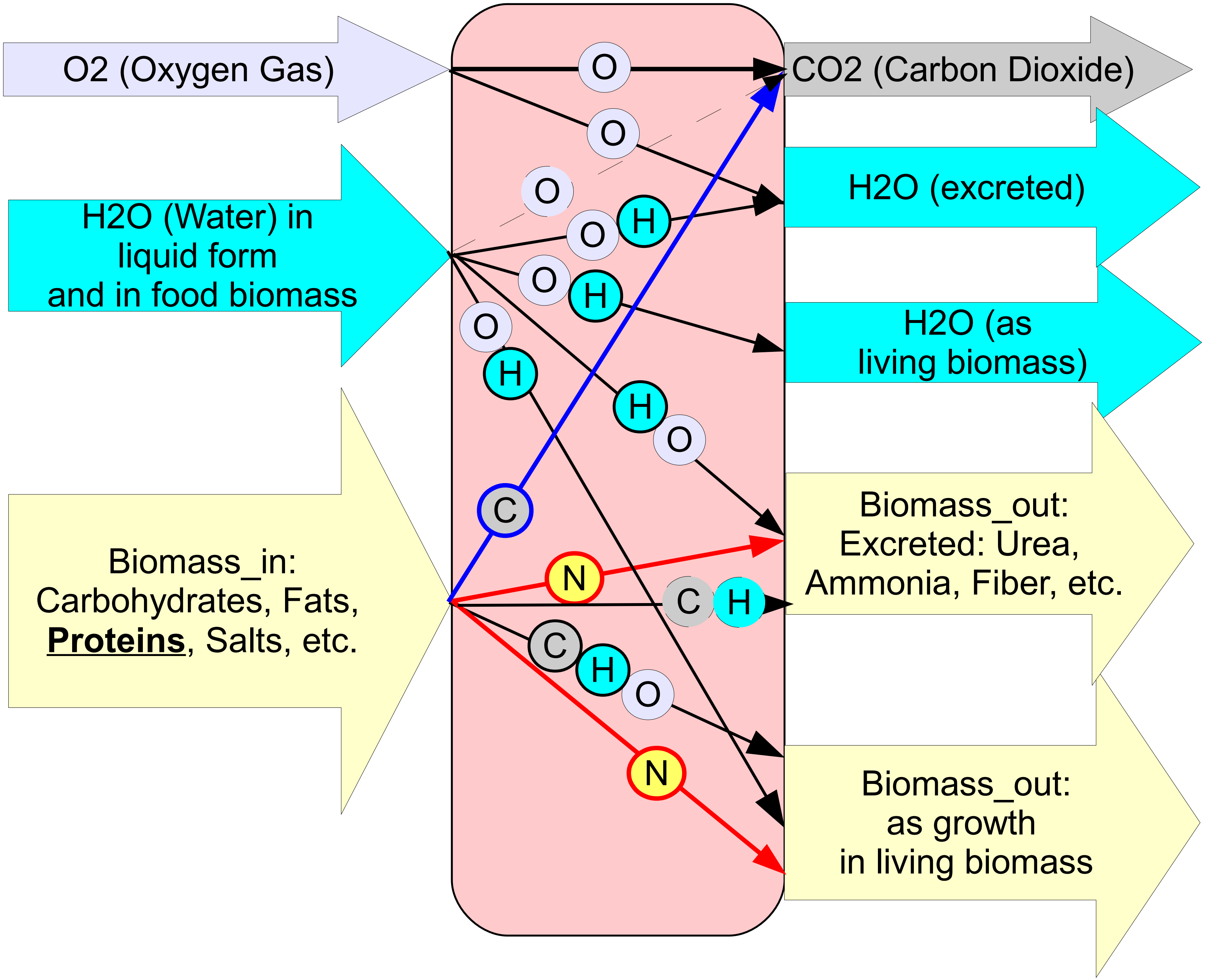
Introduction: Earth Farm as Ecosystem



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



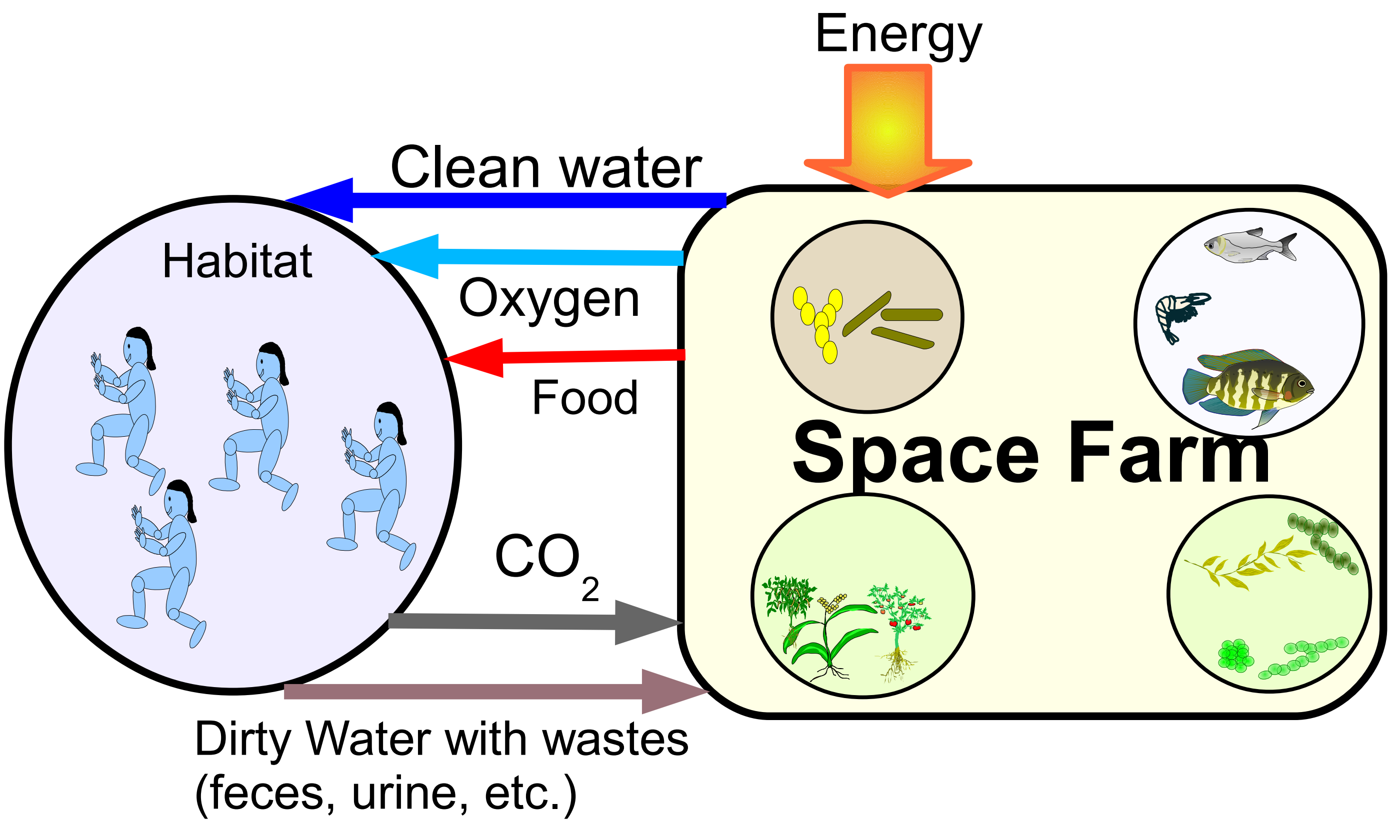
Mass Balance in Aerobic Organisms
(i.e. Yeast-Bacteria Reactor in Aerobic Mode, and Aquatics)



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

People

- Assume 100 Average Adults, static to start with
  - Will need to adjust mass balance for children, pregnant women, and older people. More mass and different populations of biomass in the farm will be needed for increasing populations.
- Assumed: sum of the food provided to the habitat must have on average per day per person:
  - 2,000 kcal
  - US RDA levels of protien, fat, carbohydrates, and fiber
  - 5 kg of water in food and to drink (most food contains lots of water fyi.)
  - ~0.6 kg Oxygen

Principles

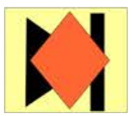
- The farm is organized into stages, each stage recirculates, and keeps optimal conditions for the organisms in the stage.
- Energy is readily available
- Only what is needed in the stage is added, and only what is produced excess is released.
- Staggered harvest: Year-round harvest, with plants and organisms of varying age offset to allow continuous supply.
  - Inital grow-out for first harvest: 1 year for all but algae and yeast. Boring menu for the first year!
- Mass Balance: Ideally the farm is built to recycle all mass, to minimize resupply.
  - In-situ materials and water to construct large farms
  - In situ or resupply for some spices, and to supply excess mass to produce export crops

Stages in the Space Farm

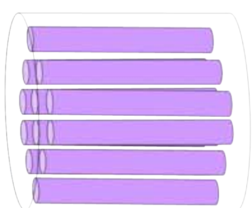
- Algae Bioreactors: Produce Algae, capture carbon from CO_2 (producing O_2) and utilize Urea in high density reactors
- Hydroponic: Growth of vascular plants for food, and to consume CO_2 (producing O_2)
- Yeast/Bacteria Bioreactor: High density set of bacteria and yeast membrane reactors. Produce CO_2 and water, and use excess oxygen. Can be used in build-out produce yeast for food. Balances biochemistry in farm.
- Aquatic: Produce foods. Converts oxygen, algae, and waste plant material into food and CO_2.

Equipment

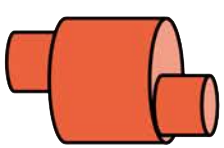

gas


liquid

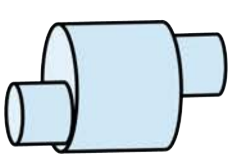
Intelligent valves: Combinations of variable valves and simple processors and sensors to control flow and direction



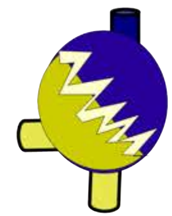
UV Sterilizer: Similar to current Pond/Pool Ultraviolet filters with multiple loops and sensors to assure sterile liquid/gas



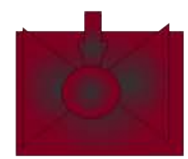
Liquid Pump: A self priming pump to push liquids (increase pressure)



Gas Pump: A pump to push gases (increase pressure)

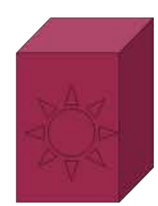


Reverse Osmosis Purifier: pushes liquid against a membrane to extract pure liquid (water) from a mixed liquid



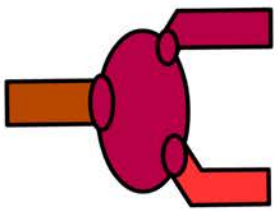
Controller w/sensor array: A complex set of routers, processors, and sensors that set conditions and control devices as directed by control software

Agitator /Infuser: A mixing blade and hose arrangement to stir thick liquids and add gasses and liquids while stiring.



Stage Control Processor: A router-multi-processor computer programmed to optimize a stage (make and keep conditions ideal to convert inputs into outputs)

More Equipment

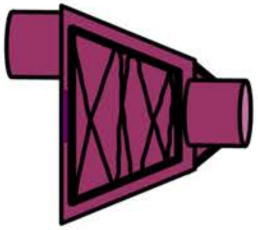


Gas Species Seperator: Pulls out one kind of gas from a mix of gasses.

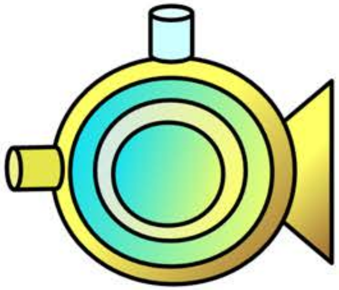
Gas Extractor (from Liquid): extracts dissolved gasses from liquid.

Mass-Liquid Seperator: Pulls solids from a liquid mix.

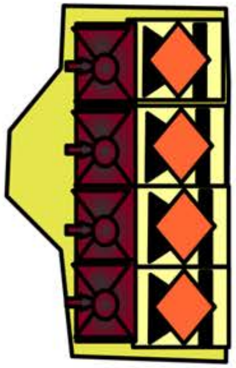
Condenser: extracts liquid from a gas mix.



Macerating pump: takes coarse solids in liquid and mixes them into a fine mixed liquid

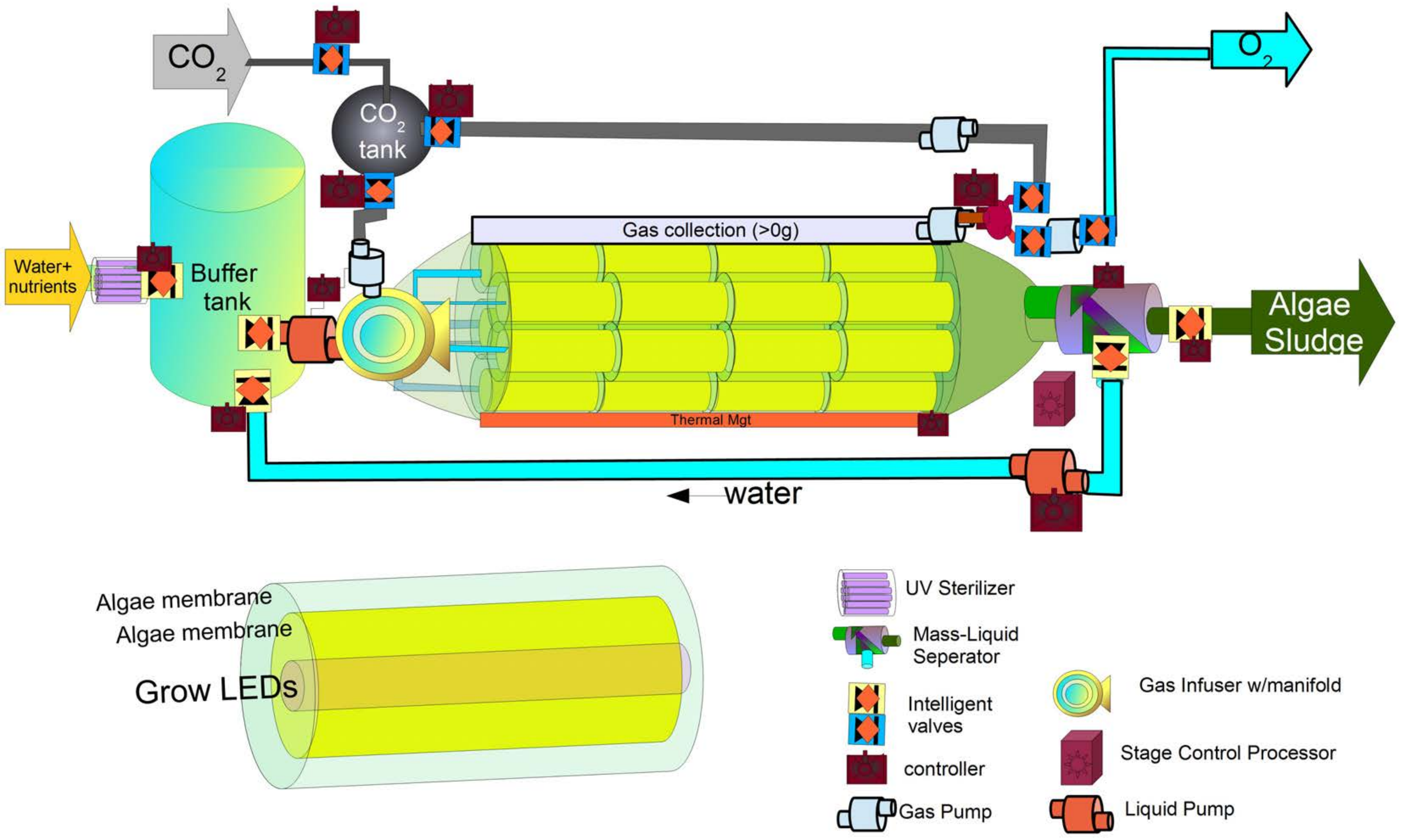


Gas Infuser w/Manifold: mixes gases into a liquid solution, then distributes the result into multiple pipes.

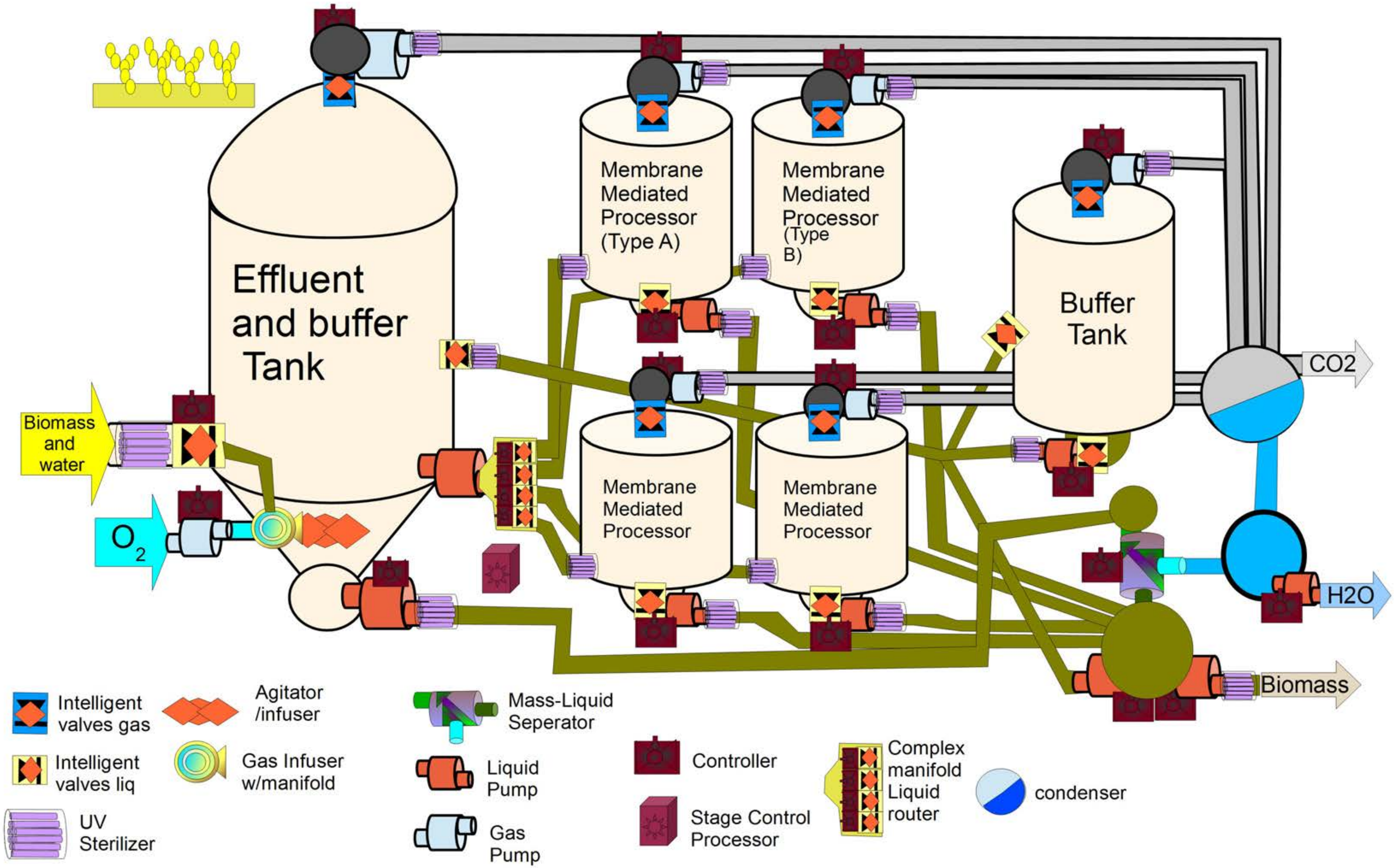


Complex Manifold Liquid Router: shuts liquids based on chemical composition.

Algae Bioreactor

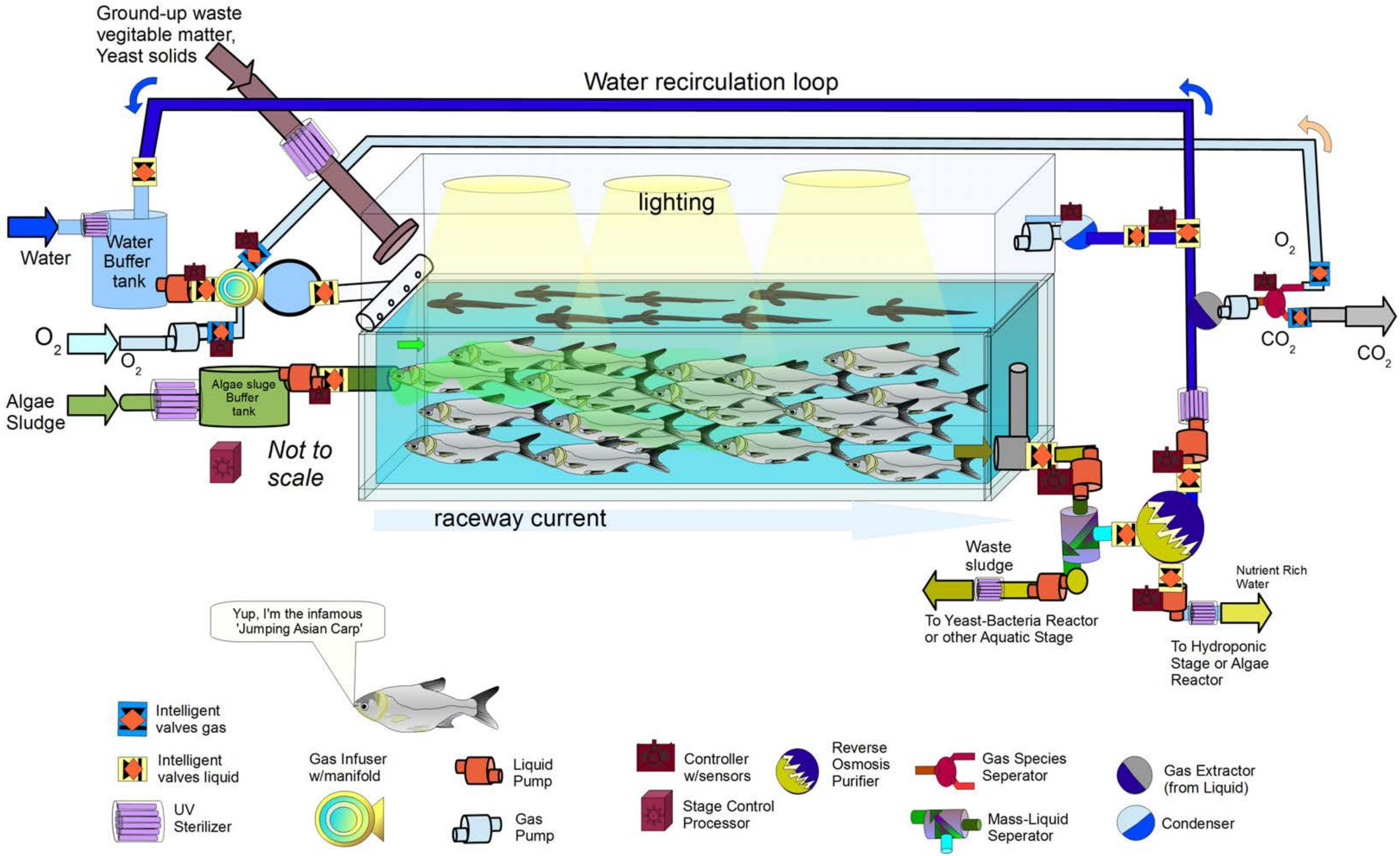


Yeast Bacteria Bioreactor Stage



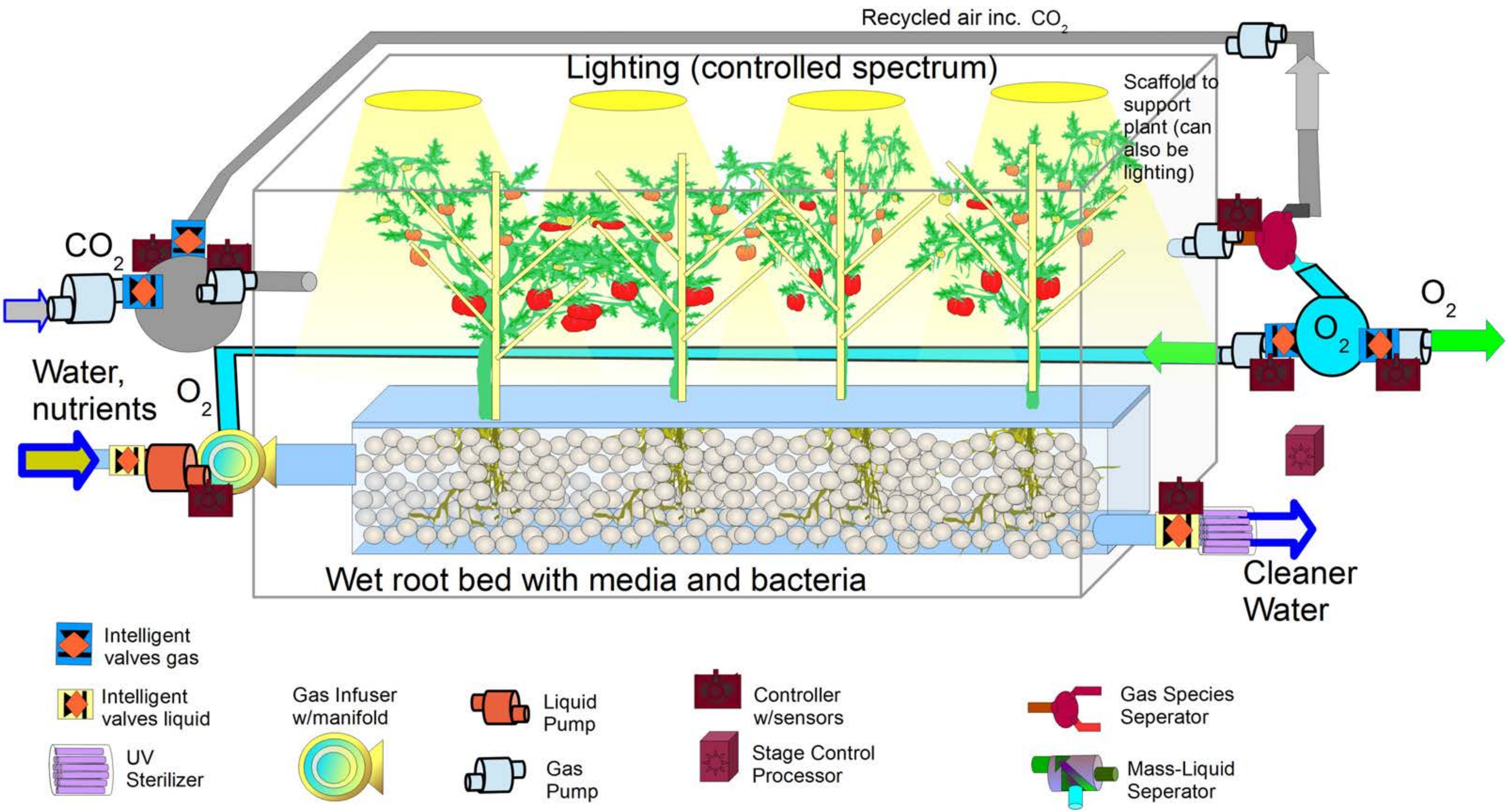
Note: Yeast-Bacteria reactor could be tuned to anerobically produce alcohol for consumption :0)

Aquatic Stage



Fish orient to light (up) and current (forward), even in low gravity. This raceway would be an ovoid tube in 0 g. Multiple raceways for juvenilles and breeders add 100% to size.

Hydroponic Stage



Lighting is distributed, not just overhead, via light tubes and light shapes.
Sections can be stacked to minimize footprint.
Atmosphere is carbon dioxide heavy (>1.5%), tending by humans in masks or robots. Rootbed is oxygen infused to facilitate nutrient uptake.

How Many? How Much?

- Assuming 9 species, ~Monte Carlo model, 130K runs

Stage	SPECIES	Scientific Name	live kg	height	Footprint (m^2)	Footprint (hectares)	Total 1 year initial supply In situ or shipped (metric tons)	g of food per person per day (raw wet mass)
Hydroponic	**Rice**	*Oryza sp. (hybrids)*	**200**	**3**	**333**	**0.03**	**0.29**	10
Hydroponic	**Tomato**	*Solanum lycopersicum (hybrids)*	**200**	**3**	**400**	**0.04**	**0.23**	150
Hydroponic	**Soybeans**	*Glycine max (hybrids)*	**19,300**	**3**	**24,125**	**2.41**	**24.19**	390
Algae Reactor	**Chlorophyta**	*Chlorophyta sp.*	**500**	**3**	**7**	**0.00067**	**0.59**	510
Algae Reactor	**Spirulina**	*Spirulina sp.*	**500**	**3**	**7**	**0.00067**	**0.54**	290
Algae Reactor	**Kelp**	*Macrocystis sp.*	**200**	**3**	**13**	**0.00133**	**0.23**	40
Aquatic	**Silver Carp**	*Hypophthalmichthys molitrix*	**7,100**	**2**	**118**	**0.012**	**10.34**	190
Aquatic	**Tilapia**	*Oreochromis sp.*	**2,500**	**2**	**42**	**0.004**	**27.53**	150
Aquatic	**Shrimp**	*Litopenaeus sp. Or Macrobrachum sp.*	**38,500**	**2**	**642**	**0.064**	**96.51**	800
Yeast-Bacteria Reactor	**Yeast-Bacteria Reactor**	*Many species on film and in tanks*	**2,430**	**3**	**32**	**0.00324**	**2.55**	
extra equipment				**3**	**771.57**	**0.0772**	**1.63**	
TOTAL					**26,491**	**2.649**	**165**	**2530**
					acres:	***6.55***		

(see AIAA 2016-5586 and further calcs)

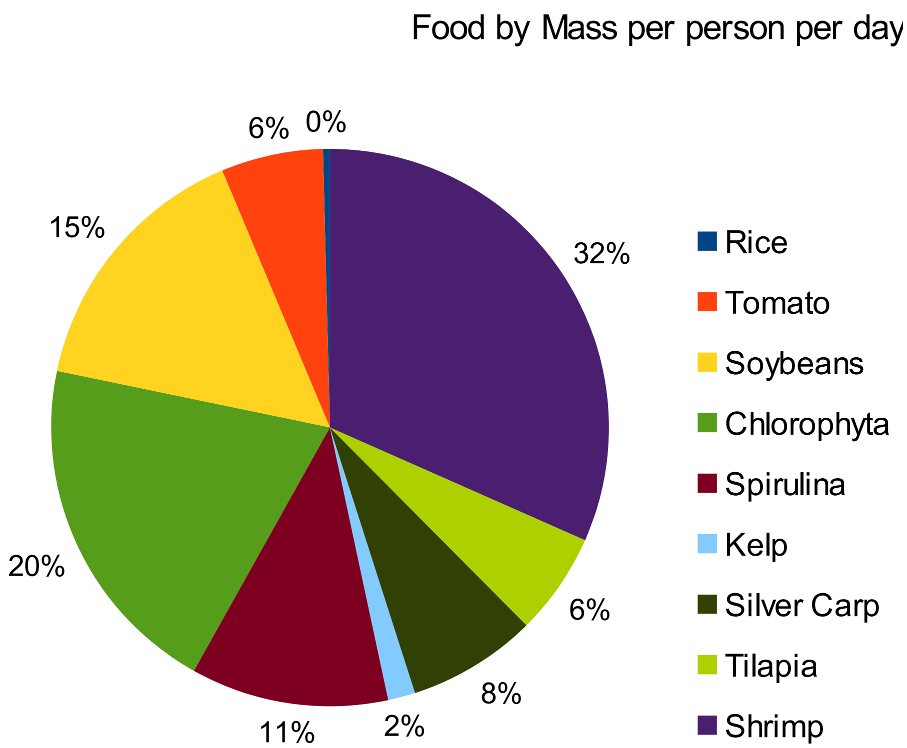
Scaled Layout (~3 hectares)

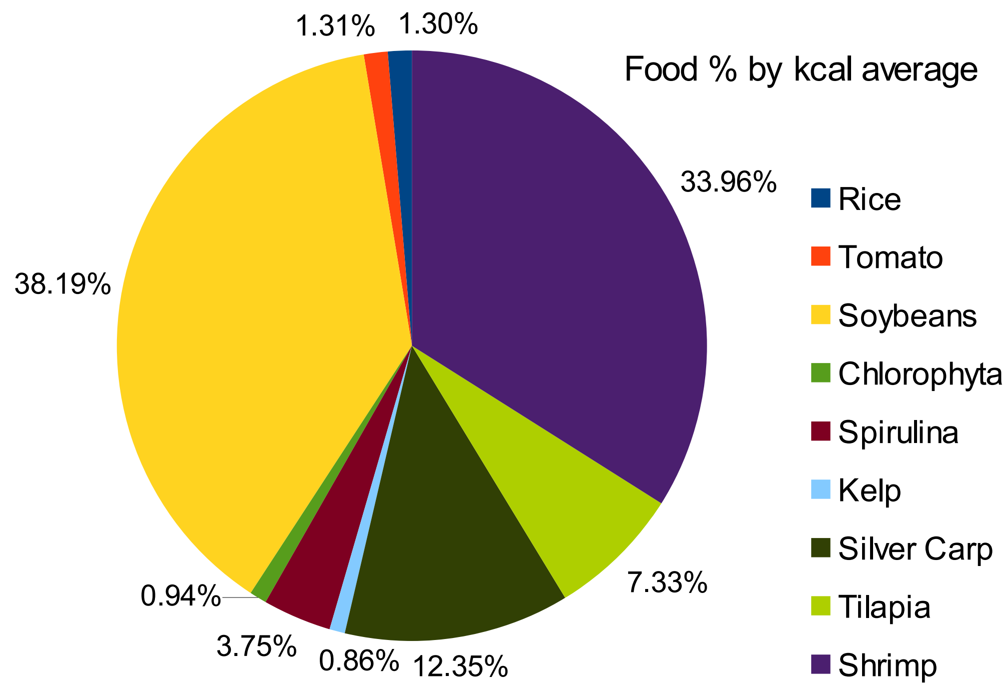
KEY

- 3@ Algae Bioreactor stages
- Yeast-Bacteria Bioreactor
- Nutrient+ Water Tank
- Waste Sludge Tank
- Food processing + storage
- Septic Tanks /Black Water
- Food Fermentation:Saki, Beer, Fish Sauce, Tofu
- Shrimp Aquatic Stage
- Silver Carp Aquatic Stage
- Tiapia Aquatic Stage
- Tomato Hydroponic Stage
- Soybean Hydroponic Stage
- Rice Hydroponic Stage
- Oxygen Gas Tanks
- Carbon Dioxide Gas Tanks
- Clean Water Tanks
- Mixed Inert Gases Tanks

Average Diet per Day

(wet mass, would cook down before ingesting)





Many other solutions are possible with these species. This is just one that fit criteria (nutritionally complete, fully recycling +/-500kg/yr).

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 grey water.
- In Habitat grown potted plants, or as hydroponic crops:
  - Sage
  - Basil
  - Mint
  - Oregano
  - Saffron
  - Ginger
  - Tumeric
  - Corriander
  - Thyme
  - Chive
  - Rosemary
  - Cumin
  - Paprika
  - Fennel
  - Mustard
  - HOPS!<<<<
- Unfortunately some common items are more difficult, requiring recipe adaptation:
  - Olives
  - Cinnamon
  - Pepper
  - Cocoa
  - Nutmeg

Other Adaptations

- Given Soybeans, soy oil is the cooking oil
- Salt can be extracted from the nutrient cycles, or mined (it will have to be part of initial supply)
- Yeast extracts are available from the Yeast-Bacteria Reactor.
- Sugar/Sweetener can be concentrated from rice.
- Fish sauce can be made from tilapia leftovers and yeasts.
- Rice can be fermented to make vinegar.

Today's Space Menu

- Fried Shrimp with kelp salad, spiced with a mix of tumeric, thyme, etc.
- pseudo-Curry Shrimp and soy noodles
- Baked Fish with fennel and sage, and tomato/kelp salad with yeast flavoring.
- Tofu soup with kelp and algae power
- Other Sides: Spiced Soy-Rice Noodles, Edamame, Steamed Rice, Soy-Cheese Analog
- Drinks: Water, tomato juice, saki, beer, rice pseudo-Mexican horchata (no cinnamon :0( ), algae juice.
- Dessert: Rice Flour Ginger Muffins

Will Improve as I add species!

Conclusions

- Space Farms are more than hydroponics!
- Future farms will likely be used to supply other stations, so will be input to output farms, species picked for price.
- Zero g farms have other considerations, but this farm would work even in microgravity, with some adaptations
- This is just beginning work!
  - Scale Physical Models
  - Increased fidelity in metabolic models
  - Far more species in AIAA SPACE 2017 paper.

References

[0] Meyer, B.L. Shepard, N.S.,. "Nutrient Balance and Nitrogen Cycling In a Multistage, Multispecies Space Farm", AIAA SPACE 2016, AIAA SPACE Forum, (AIAA 2016-5586)

[1] Meyer, B.L., "Of Fruits and Fishes: A Space Farm and Recycling Concept", AIAA SPACE 2015 Conference and Exposition, SPACE Conferences and Exposition, (AIAA 2015-4607)

[2] Wieser, M., Holden, N., Coplen, T., Böhlke, J., Berglund, M.,Brand, W. et al. Atomic weights of the elements 2011 (IUPAC Technical Report), Pure Appl. Chem. Research Triangle Park, NC: International Union of Pure and Applied Chemistry, 2013.

[3] Jones, H. "Design Rules for Life Support Systems, 33rd International Conference on Environmental Systems (ICES) ." ICES40, 2003-01 -2356. Vancouver, BC: Society of Automotive Engineers, Inc, 2003. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040012725.pdf.

[4] Guidance for Industry: A Food Labeling Guide,US Food and Drug Administration, January 2013 http://www.fda.gov/downloads/Food/GuidanceRegulation/UCM265446.pdf.

[5] Hausman, R. E.; Cooper, G. M. The cell: a molecular approach. 2004. Washington, D.C: ASM Press. ISBN 0-87893-214-3.

[6] Reeds, P.J.,Dispensable and Indispensable Amino Acids for Humans ,J. Nutr. July 1, 2000 vol. 130 no. 7 1835S-1840S.

[7] United States Department of Agriculture, Agricultural Research Service, National Nutrient Database for Standard Reference Release 28, May, 2016 Software v.2.6.1, https://ndb.nal.usda.gov/ndb/foods.

[8] Pearce, G.R., Lee, J.A., Simpson, R.J., Doyle, P.T. , "Sources of variation in the nutritive value of wheat and rice straws", Plant breeding and the nutritive value of crop residues, JUNE 1988 INTERNATIONAL LIVESTOCK CENTRE FOR AFRICA, http://www.fao.org/Wairdocs/ILRI/x5495E/x5495e00.htm.

[9] Tang, L. , Zhu, Y. , Hannaway, D. ,Meng, Y. ,Liu, L., Chen, L., Cao, W. , "RiceGrow: A rice growth and productivity model",NJAS - Wageningen Journal of Life Sciences, Volume 57, Issue 1, December 2009, Pages 83–92, doi:10.1016/j.njas.2009.12.003, http://www.sciencedirect.com/science/article/pii/S1573521409000153

[10] ed. Manns, R., Schmidt, S., Beveridge, C., PLANTS IN ACTION A resource for teachers and students of plant science,2nd ed., © Australian Society of Plant Scientists, New Zealand Society of Plant Biologists, and New Zealand Institute of Agricultural and Horticultural Science 2010–2016, http://plantsinaction.science.uq.edu.au/content/about

References (2)

[11]Xing,Y. Wang, , R. ,Sun, W. , An, J. , Wang, C.X. , H.J. Bao, L. Gong, X. Z.Wang, "Effect of Balanced Fertilization on Rice Nutrient Uptake, Yield, and Profit", Better Crops/Vol. 93 (2009, No. 1), http://www.ipni.net/publication/bettercrops.nsf/0/5C6E09CE82D30C7385257980007O212E/$FILE/Better%20Crops%202009-1%20p4.pdf

[12]Wu, C. ,Feng,Y. , Shohag,M. J. I., Lu, L. , Wei, Y., Gao, C. , and Yang, X., "Characterization of 68Zn uptake, translocation, and accumulation into developing grains and young leaves of high Zn-density rice genotype", J Zhejiang Univ Sci B. 2011 May; 12(5): 408–418. doi: 10.1631/jzus.B1000291, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3087098/.

[13]Mueller, N. , "Plant Nutrient Analysis: Do your soybeans have the right stuff?" 7/25/2013, iGrow, South Dakota State University Brookings, SD. http://igrow.org/agronomy/profit-tips/plant-nutrient-analysis-do-your-soybeans-have-the-right-stuff/#sthash.eHjNCXoD.dpuf.

[14]"Soybean Growth and Development"February 19, 2015, Corn Agronomy, University of Wisconsin, 1575 Linden Drive - Agronomy, Madison WI 53706, http://corn.agronomy.wisc.edu/Crops/Soybean/Default.aspx

[15]Pedersen, P., "Soybean Growth Stages", ISU Extension publication, Soybean Growth and Development, 4/9/07, Copyright 2003-2016. , Iowa State University Extension.

[16]Hill, W., Pegg, M. Evaluating Asian Carp Colonization Potential and Impact in the Great Lakes Final Report to Illinois-Indiana Sea Grant. Champaign, IL: Sea Grant, 2008.

[17]Kapetsky, J.M.; Nath, S.S. A strategic assessment of the potential for freshwater fish farming in Latin America. COPESCAL Technical Paper. No. 10. Rome, FAO. 1997. 128p, ISBN 92-5-103989-5 http://www.fao.org/docrep/005/W5268E/W5268E00.htm#TOC

[18]Rakocy, J.E., Tank Culture Of Tilapia,The Fish Site, 5m Publishing, 01 Nov2005, Sheffield, S35 1QN, England. http://www.thefishsite.com/articles/136/tank-culture-of-tilapia/

[19]Kungvankij, P. , and Chua, T.E. , Shrimp Culture: Pond Design, Operation And Management, NACA Training Manual Series No. 2, Food and Agriculture Organization of the United Nations and Network of Aquaculture Centres in Asia (NACA), June 1986, http://www.fao.org/docrep/field/003/ac210e/AC210E00.htm#TOC.

[20]Walker, S. J., ECOPHYSIOLOGY OF GROWTH IN THE PACIFIC WHITE SHRIMP (LITOPENAEUS VANNAMEI), Dissertation, Texas A&M University, May 2009

References (3)

[21]Davis, D. A. , Rouse, D.,Amaya, E., Zelaya, O.Venero, J. Quintero,H. , "Historical Review Of Feeding Protocols For The Pacific White Shrimp Litopenaeus Vannamei At Claude Peteet Mariculture Center, Gulf Shores, Alabama", AQUA 2006, World Aquaculture Society, Louisiana State University, Baton Rouge, LA, 2006.

[22]Reed D.C., Rassweiler A, Arkema K.K., "Biomass rather than growth rate determines variation in net primary production by giant kelp",Ecology. 2008 Sep;89(9):2493-505.

[23]Danesi, E.D., Rangel-Yagui, C.O.,Sato, S., Monteiro de Carvalho, J.C., "Growth and Content of Spirulina Platensis Biomass Chlorophyll Cultivated at Different Values of Light Intensity and Temperature Using Different Nitrogen Sources",Braz J Microbiol. 2011 Jan-Mar; 42(1): 362–373. doi: 10.1590/S1517-83822011000100046, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3768952/.

[24]Pena, J. "Greenhouse Vegetable Production Economic Considerations, Marketing, and Financing." 30 05 2005. Texas A&M AgriLife Extension Service. 2015. http://aggie-horticulture.tamu.edu/greenhouse/hydroponics/economics.html.

[25]Productivity: Crop Water Information: Tomato,WATER, FAO, 2015 http://www.fao.org/nr/water/cropinfo_tomato.html

[26]Ulissi, V., Antonucci, F. ,Benincasa P., Farneselli M., Tosti G., Guiducci M., Tei F.,Costa C., Pallottino F. , Pari L. and Menesatti P.,"Article Nitrogen Concentration Estimation in Tomato Leaves by VIS-NIR Non-Destructive Spectroscopy", Sensors 2011, 11, 6411-6424; doi:10.3390/s110606411 sensors ISSN 1424-8220 www.mdpi.com/journal/sensors

[27]Van Hoek,P., Van Dijken,J.P.,and Pronk,J.T. "Effect of Specific Growth Rate on Fermentative Capacity of Baker's Yeast", Appl Environ Microbiol. 1998 Nov; 64(11): 4226–4233.

References (4)

[28]Doucha, J., Straka, F., Livansky, K. "Utilization of flue gas for cultivation of microalgae (Chlorella sp.) in an outdoor open thin-layer photobioreactor." Journal of Applied Phycology (2005): 403–412.

[29]Phukana M.M., Chutiab R.S., Konwara, B.K., Kataki, R. . “Microalgae Chlorella as a potential bio-energy feedstock”, Applied Energy 88(10):3307-3312 · September 2011

[30]Belasco, Warren (July 1997). "Algae Burgers for a Hungry World? The Rise and Fall of Chlorella Cuisine". Technology and Culture 38(3): 608–34.doi:10.2307/3106856.JSTOR 3106856, https://www.jstor.org/stable/3106856.

[31]“Seaweed, Chlorella, Dried” Nutrition facts, SELF Magazine, 2014 Condé Nast. http://nutritiondata.self.com/facts/custom/569428/2.

[32]Csavina JL, Stuart BJ, Riefler RG, Vis ML., “Growth optimization of algae for biodiesel production”,J Appl Microbiol. 2011 Aug;111(2):312-8. doi: 10.1111/j.1365-2672.2011.05064.x. Epub 2011 Jun 23.

[33]Lürling, M., Eshetu, F., Faassen, E. J., Kosten, S. And Huszar, V. L. M. (2013), Comparison of cyanobacterial and green algal growth rates at different temperatures. Freshwater Biology, 58: 552–559. doi:10.1111/j.1365-2427.2012.02866.x.

[34]Seltz, J. MEDITERRANEAN REGIONAL AQUACULTURE PROJECT, TECHNICS USED FOR INTENSIVE REARING AND ALIMENTATION OF FISH AND SHELLFISH, "Rearing Structures For Aquaculture" Ch. 10. Motta di Livenza, Itally: Food and Argicultural Organization of the United Nations, 1986.

BACKUP SLIDES

Space farm concepts typically balance mass at a course level, but omit the devices and species that will be needed for air, food, and water for colonists. They also should show the nutrition of the humans, the menus that emerge, and the populations and sizes of vegetable, algae, and animal species. This presentation fills in these gaps using a software model and various designs, shows possible meals that may emerge given complex combinations of species, and shows population sizes, concept layout, and footprint.

Saturday 27 May

11:25 - 11:45 Space Farm Meyer abstract

What Does a Person Need?

From AIAA-2016-5586

Inputs per person per day: 5kg Water in food and drink, 0.59 kg Oxygen, and at least .07 kg Fats, 0.32 Carbohydrates, 0.025 kg Fiber, 0.05 kg Proteins, and 2,000 kcal.

Outputs per person per day: 0.034 kg Dry biomass (Excreted), 0.81 kg CO_2, 5.2 kg Water

Human inputs per person		**%% by mass**				**kg mass**			
Nutrient (Dry Biomass in)	**kg/person/day**	**C**	**O**	**H**	**N**	**C**	**O**	**H**	**N**
Lipids+Cholesterol	0.0703	**83.87%**	4.14%	11.99%	0.00%	0.059	0.003	0.008	0.000
Carbohydrates	0.3240	**42.11%**	51.41%	6.48%	0.00%	0.136	0.167	0.021	0.000
Cellulose (Fiber)	*0.0250*	*44.45%*	*49.34%*	*6.22%*	*0.00%*	*0.011*	*0.012*	*0.002*	*0.000*
Proteins	0.0500	**45.28%**	30.11%	7.20%	14.88%	0.023	0.015	0.004	0.007
NET Oxygen in**	0.5900	0	100.00%	0	0	0.000	0.590	0.000	0.000
Water in*	5.0000	0.00%	88.81%	11.19%	0.00%	0.000	4.441	0.559	0.000
NET INPUT	**6.059**					**0.229**	**5.227**	**0.594**	**0.007**
USABLE INPUT (i.e. Input -cellulose)	6.034					0.22	5.22	0.59	0.01
Excrete (Dry Biomass out)	0.034					0.008	0.007	0.011	0.007
Carbon Dioxide	0.811	27.29%	72.71%	0.00%	0.00%	0.221	0.590	0.000	0.000
Water out	5.214	0.00%	88.81%	11.19%	0.00%	0.000	4.631	0.583	0.000
NET OUTPUT	**6.059**					**0.229**	**5.227**	**0.594**	**0.007**
** = Includes water in wet biomass from foods, assumes 3 liters drink, and 2 liters in food*									
*** = NET Oxygen in is Oxygen inhaled – minus Oxygen exhaled*									

NASA guidance[3], and US Recommended Daily Allowance for a 2,000 kcal diet[4]

Example Mass Flows, 9 Species

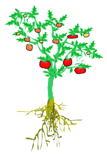
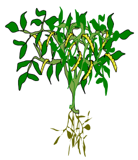
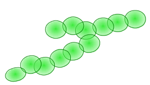
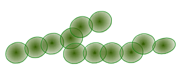
- Using a Monte-Carlo Analysis and a series of near-ideal assumptions, using 9 species, a series of mass flows from AIAA-2016-5586 with updates, 100 colonists, by day:

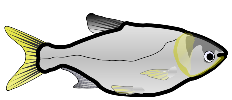
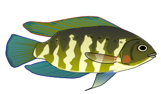
Algae Reactors	Net In (kg)	Net Out (kg)
Gases	2.83	2.15
Dry Biomass	0.39	1.87
Liquids and water in wet biomass	90.42	89.62
Living Biomass (wet, total) kg	1200	cell mass bound to membranes

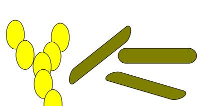
Yeast-Bacterial Reactor	Net In (kg)	Net Out (kg)
Gases	913	993
Dry Biomass	470	9
Liquids and water in wet biomass	10	391
Living Biomass (wet, total) kg	2786	includes effuent tank cells and cells bound to membranes

Species Examined

From *AIAA-2016-5586*

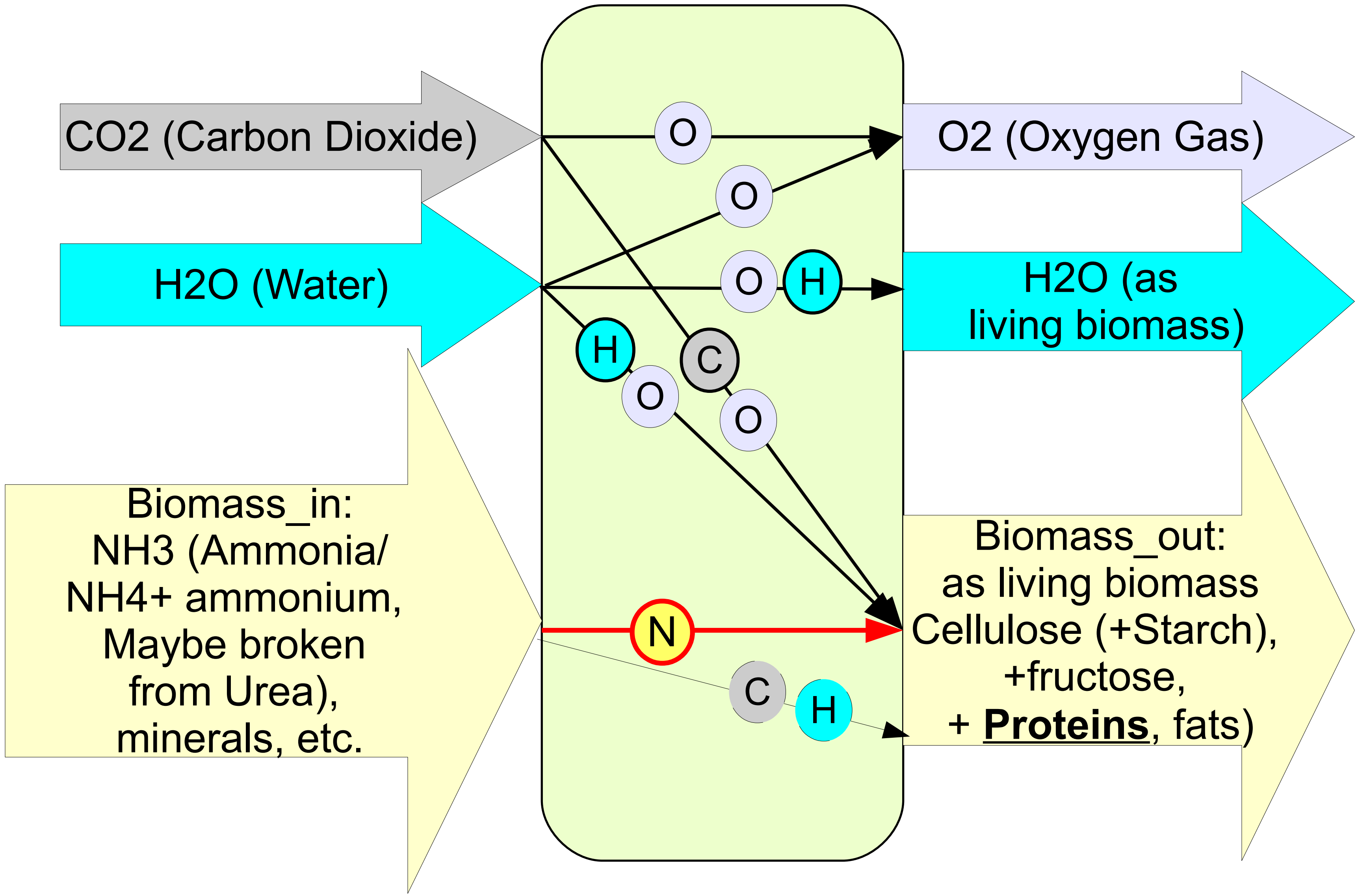






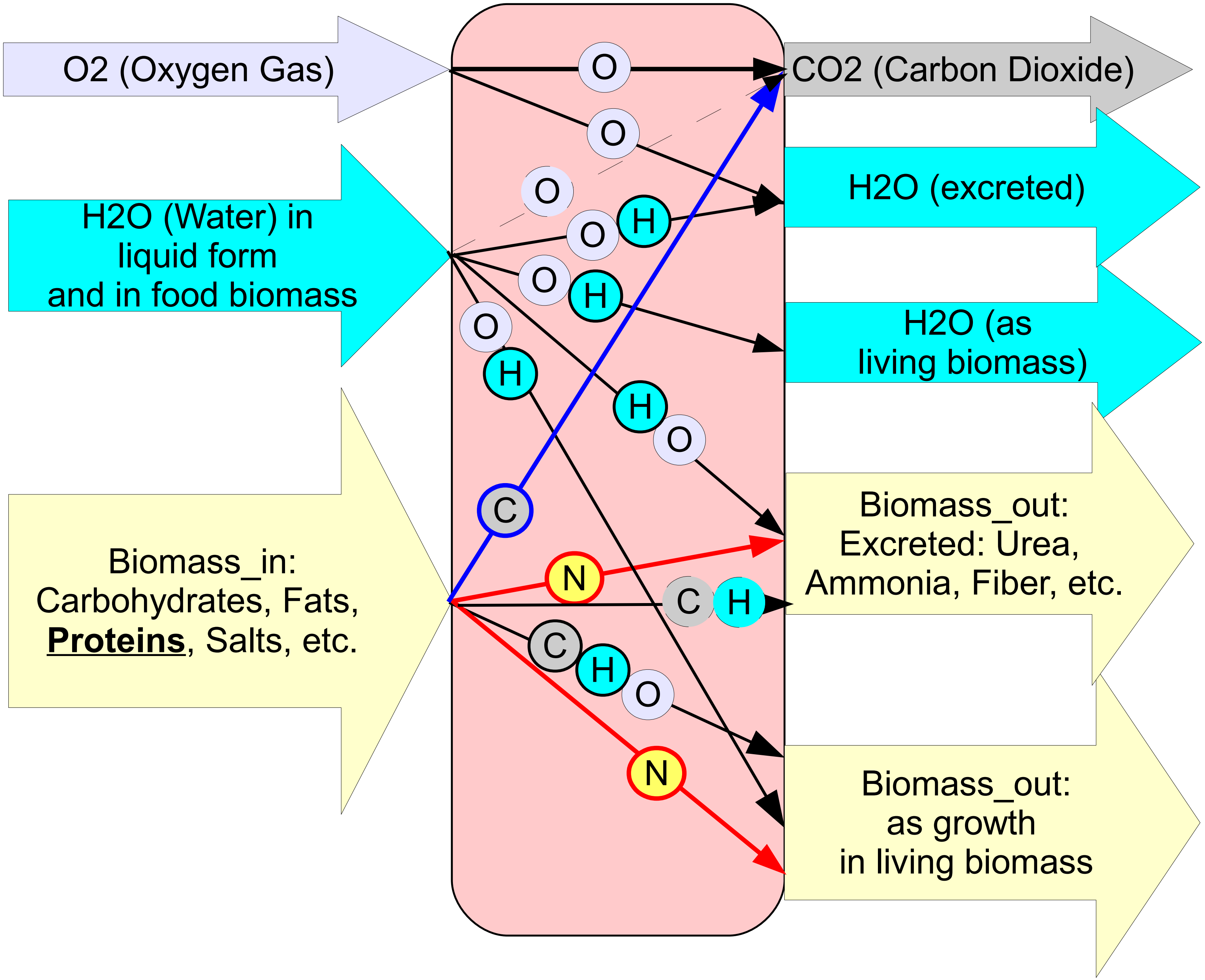


SPECIES	Scientific Name	Dietary Source	Metabolic Sources	Assumptions
Rice	*Oryza sp. (hybrids)*	USDA NDD #20088[7]	8,9,*10,11,12*	Efficiency is equal or greater than field production, entire plant is harvested, including roots. Planting and growth is staggerd for continuous production
Tomato	*Solanum lycopersicum (hybrids)*	USDA NDD #11529[7]	1,24,25,26	Plants are picked for fruit, and trimmed to stay the same size continuously
Soybeans	*Glycine max (hybrids)*	USDA NDD #11450[7]	13,14,15	Efficiency is equal or greater than field production, entire plant is harvested, including roots. Planting and growth is staggerd for continuous production
Chlorophyta	*Chlorophyta sp.*	Ref 30, Nutrtion facts, compared to Ref 29	28,29,30,31,32	Doubled biomass is consumed as edible biomass by humans or animals
Spirulina	*Spirulina sp.*	USDA NDD #11666[7]	22	Doubled biomass is consumed as edible biomass by humans or animals
Kelp	*Macrocystis sp.*	USDA NDD #11445[7]	21	All plant is edible. Growth is continuously trimmed to provide edible biomass
Silver Carp	*Hypophthalmichthys molitrix*	USDA NDD #15008[7]	16	Entire mature organism is consumed. Breeders and small juvenilles are a very small mass relative to crop. Crop is staggered to allow continuous harvest and replacement.
Tilapia	*Oreochromis sp.*	USDA NDD #15261[7]	17,18	Entire mature organism is consumed. Breeders and small juvenilles are a very small mass relative to crop. Crop is staggered to allow continuous harvest and replacement.
Shrimp	*Litopenaeus sp. Or Macrobrachum sp.*	USDA NDD #15270[7]	19,20,21	Entire mature organism is consumed. Breeders and small juvenilles are a very small mass relative to crop. Crop is staggered to allow continuous harvest and replacement. Growth is at least as good as pond rearing.
Yeast-Bacteria Reactor	Many species on film and in tanks	USDA NDD #18375[7]	27	Excretes produced only from protein aerobic or anerobic respiration, edible biomass only produced as needed if the system is lacking biomass

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)