Keto in Space: Protein Targeted Space Agriculture and How it Affects Overall Mass Flow

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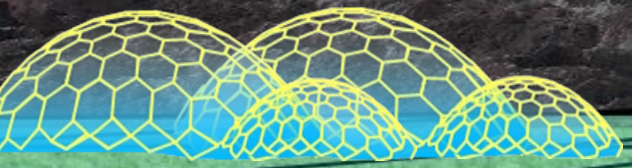

NSS NATIONAL SPACE SOCIETY

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ST. LOUIS SPACE FRONTIER

Overview

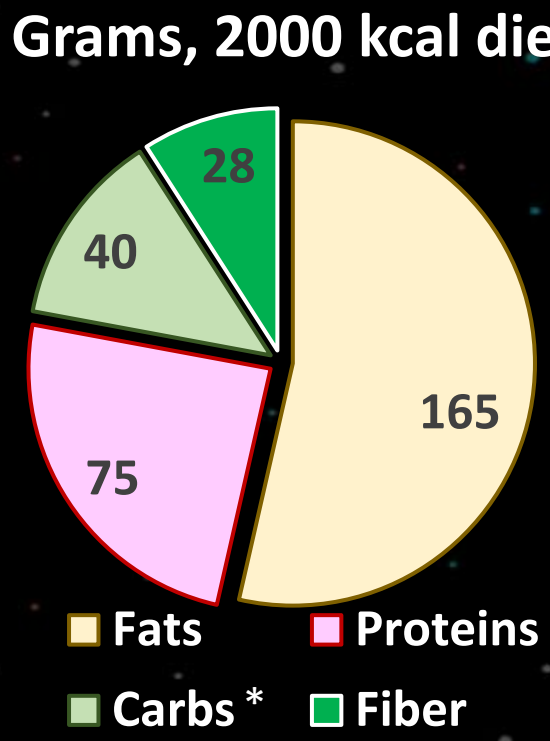
- What is a Keto Diet?
- What Crop Options lead to Keto-friendly Menus
- Farm dynamics for each option: Changes in Size, Key Mass Flows, and Tradeoffs

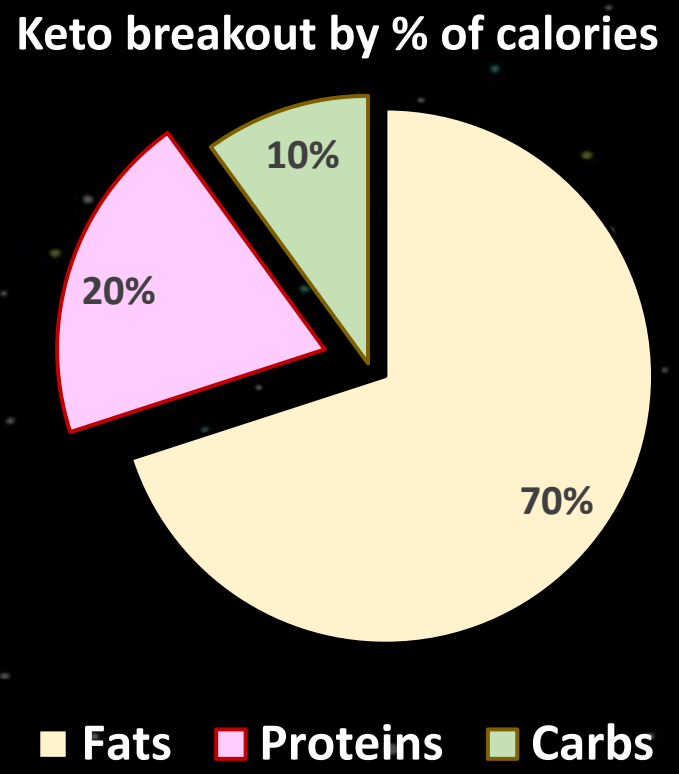
Ground Rules

- Space Settlement is less than 3 years old (determines crop options)
- Keto eaters are a minority of the population
- Bell Peppers are a stand in for most vine veggies (i.e. tomatoes, etc.)
- Rice is a stand in for most grains
- Diet Options include:
  - Vegan, min processing (e.g. roasting peanuts, etc.)
  - Vegan, heavy processing but no peanuts (e.g. includes fermentation)
  - Vegan, processed foods and peanuts
  - Seafood proteins (kosher, non-kosher, etc.)
  - Insect proteins
  - Birds (kosher, non-kosher, etc.)
  - Rabbits
  - Multi-mix

What is a Keto Diet?

- Ketogenic diets focus on fats and protein as calorie sources, minimizing (calorie containing) carbohydrate intake to force the body to burn body fat while preserving lean muscle
- Paleo diets are similar but focus on unprocessed foods.
- Fiber >28g, higher is better
- Carbs* = Calorie containing carbohydrates





Ratio by mass of (Fat+ Protein+ Fiber+ Ash)/ (Caloric Carbohydrates) should be > 7

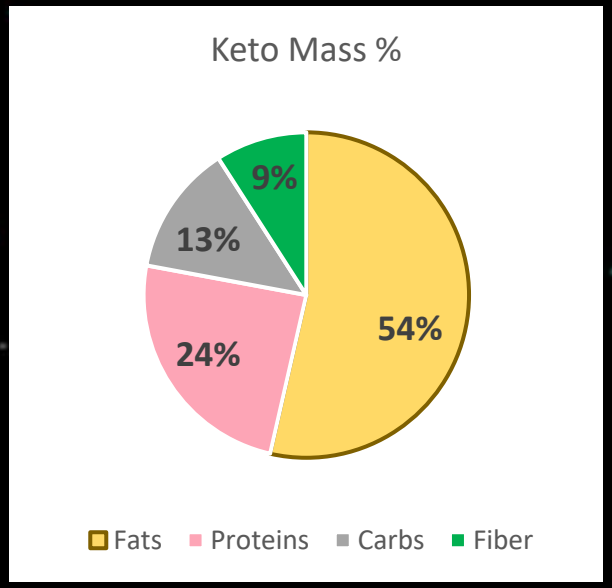
Adapted from data in: "Diet Review: Ketogenic Diet for Weight Loss"
The Nutrition Source, Harvard School of Public Health plus US RDA recommendation for Fiber

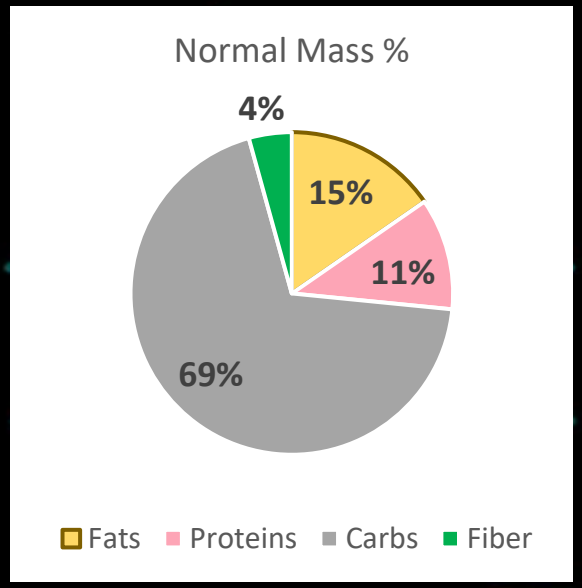
Sorry, no almonds, cashews, pecans…or larger livestock

- On Earth these are keto staples. Given 3-year condition some crops are out.
- Trees are unlikely to be productive at scale yet, even if shipped whole and alive. These trees take decades from seed or cultivar to be fully productive. Parks might have a few for treats at most in 3 years.
  - This leaves the only annual keto ‘nut’: Peanuts
  - Sunflowers and Soybeans a close second.
- A herd of goats, sheep, cattle take years to establish at scale, and lots of room. Also take lots of feed and waste processing. So, no meat from these.

Fats are king, Nitrogen a must

- Fats are king in Keto. Fats are 10x higher that normal US RDA
  - Drives oil crops, or processing to concentrate fats to oils
- Carbs are far lower: 1/10th or less of normal US RDA
- Nitrogen is around 15% of proteins, and keto is higher protein, usually due to the quest to gain calories
- Drives push to legumes, meats, nuts……with fiber





Unprocessed Green Crops

			Dry Mass Components					
Crop	% water	Kcal/kg (wet)	Proteins	Fats	Carbs*	Fiber	Ash	(Fat+P+F+A)/C
Peanuts (Raw)	7%	5630	28%	53%	8%	9%	2%	11.29
Sunflowers (Seed)	5%	6090	20%	51%	18%	8%	3%	4.56
Soybeans (Raw)	9%	4460	40%	22%	23%	10%	5%	3.38
Soybean Sprouts	69%	1220	42%	22%	27%	4%	5%	2.70
Cyanobacteria	90%	260	61%	4%	25%	4%	6%	3.00
Green Algae (cellular)	90%	383	61%	10%	24%	4%	1%	3.17
Duckweed	93%	2913	25-40%	3%	28%	26%	18%	>2.57
Lettuce (Arugula)	92%	250	31%	8%	25%	19%	17%	3.00
Cabbage	92%	250	17%	1%	42%	32%	8%	1.38
Bell Peppers	94%	230	12%	2%	66%	15%	5%	0.52
Pinto Beans	11%	3470	10%	3%	70%	11%	6%	0.43
Quinoa	13%	3680	15%	6%	68%	7%	3%	0.46
Rice	10%	3700	9%	4%	83%	3%	1%	0.20
KETO ideal			> 24%	> 54%	< 13%	> 9%		> 7

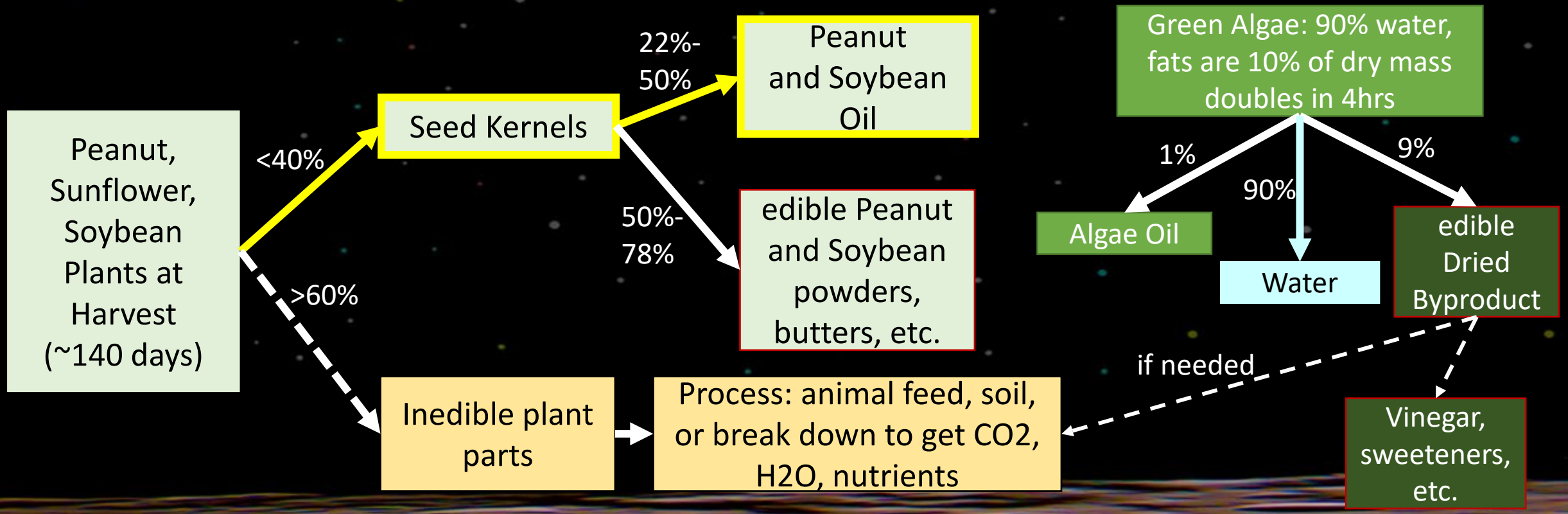
Big Calorie Crops…keto problematic

- Potatoes and Legumes (inc. Peanuts) plants take up roughly the same room in a field ($1m^3$) and grow similarly in time (all ~120 days)
- Potatoes and grains are a no-go for Keto…so it takes 3 times more area to go keto in plants

Crop	Kcal/sq meter	Fat+P+A+fiber/ carbs
Potatoes	4774	0.70
Corn	3127	0.34
Rice	2486	0.20
Pinto Beans	1162	0.43
Quinoa	3680	0.46
Soybeans	**1825**	**3.38**
Sunflowers	**1089**	**4.56**
Peanuts	**1466**	**11.29**

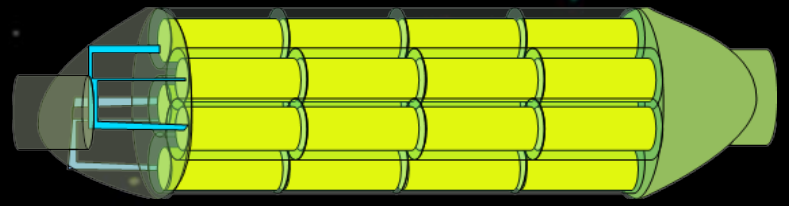
Oil Trade offs: Peanuts, Soybeans, Sunflowers or Green Algae?

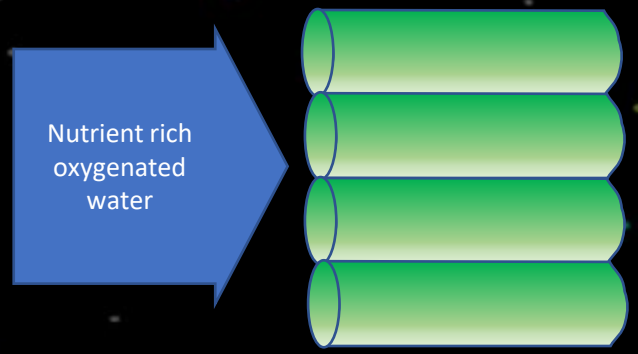
- Due to mass flow, growing vascular plants just to primarily get oils (Fats) is size and energy inefficient, even though they are higher in fat content…doesn't mean you don't want them though.



Core Technologies: Photobioreactors

- High Density Machinery to grow cyanobacteria, algae, or edible water plants (all called ‘algae’ for simplicity here).
- Can be open format or use membrane or mesh confined algae
- Shape optimizes exposure of algae to CO2 and nutrient infused solution and light
- Like sleeves for hydroponics, a low weight reactor shape is a drape or sheet reactor, with free flowing algae, with external lighting
- Lights can be immersed or external
- Products are whole algae cells (90% water), cleaner water, and oxygen.
- Pros: Much more compact than hydroponics, especially for early settlements, very fast to first harvest (a few days after switch on).
- Cons: Requires whole machines, lights, and control systems. Algae can be very fragile.
- Can be used to make human food, or food for animals (esp. aquatic organisms, insects)





Note : for free flowing algae, pumps must not use impellers (i.e. be fluidic pumps or slow stirrers)

A few day options: Vegan Keto (2000 kcal), (Fat+P+F+A)/C =7+/-, w/nutritional mins

Glop

Crop	Grams included
Algae Oil	185
Yeast	140
Cyanobacteria	150

Vegan, no processing

Crop	Grams included
Peanuts (Raw)	345
Sunflowers (Seed)	10
Lettuce (Arugula)	110

Vegan, no peanuts

Crop	Grams included
Sunflowers (Seed)	10
Algae Oil	175
Lettuce (Arugula)	150
Brewer's Yeast	10
Lion's Mane	30
Tofu	405
Kimchi	5

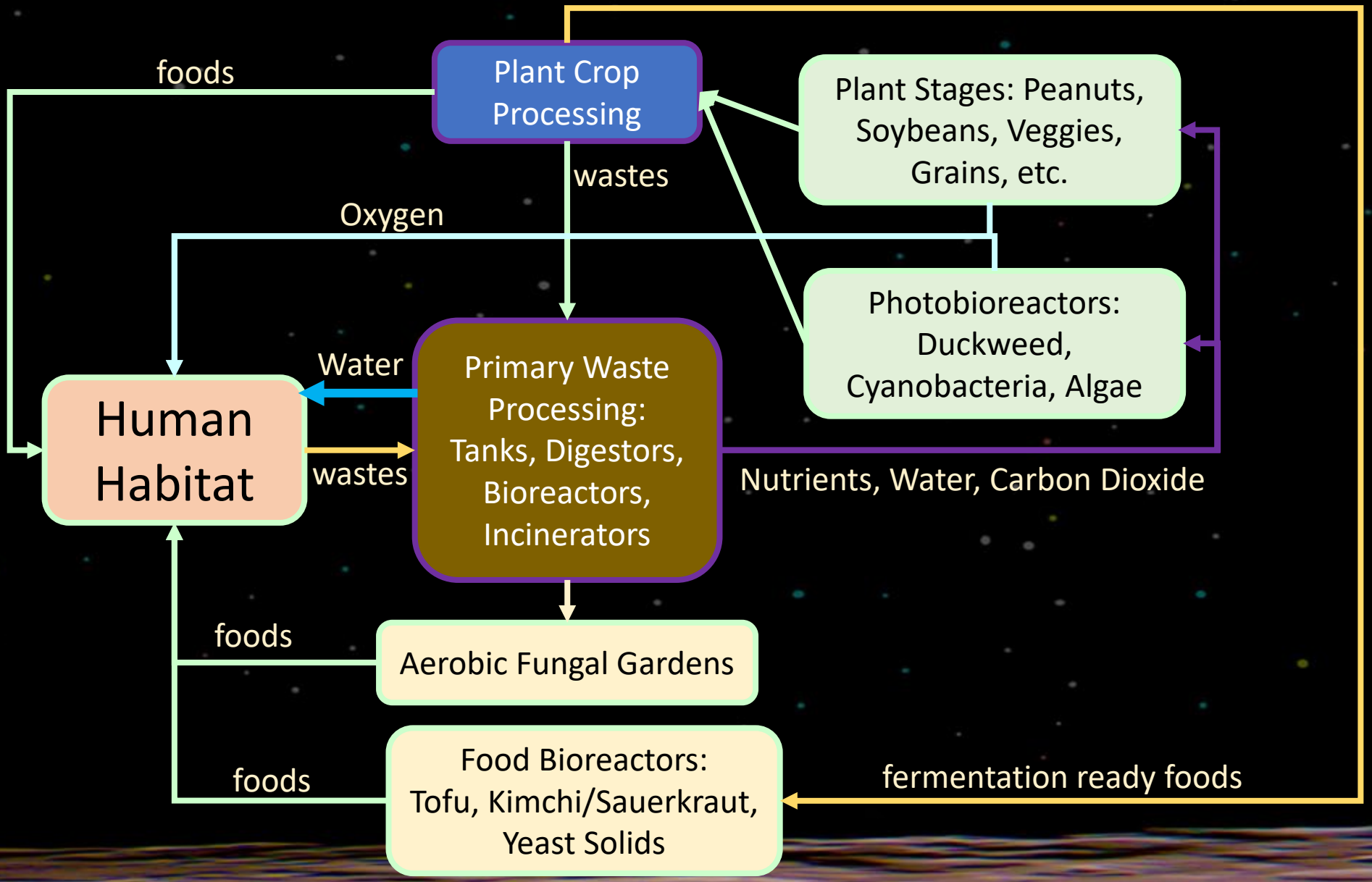
Vegan, processing and peanuts

Crop	Grams included
Peanuts (Raw)	30
Sunflowers (Seed)	10
Algae Oil	176
Lettuce (Arugula)	150
Oyster Mushrooms	20
Tofu	300
Kimchi	5

Fungi, Tofu, Kimchi

			Dry Mass Components					
Crop or Product	**% water**	**Kcal/kg (wet)**	**Proteins**	**Fats**	**Carbs ***	**Fiber**	**Ash**	**(Fat+P+F+A)/C**
Brewer's Yeast	5%	3250	43%	8%	15%	28%	6%	5.67
Lion's Mane	89%	430	23%	2%	28%	38%	9%	2.57
Oyster Mushrooms	89%	410	31%	4%	35%	21%	9%	1.86
Shiitake Mushrooms	89%	440	21%	2%	35%	37%	5%	1.86
Tofu	82%	830	30%-56%	27%-30%	1%-15%	6%	7%-28%	6+
Kimchi	94%	150	19%	9%	14%	28%	30%	6.14
KETO ideal			> 24%	> 54%	< 13%	> 9%		> 7

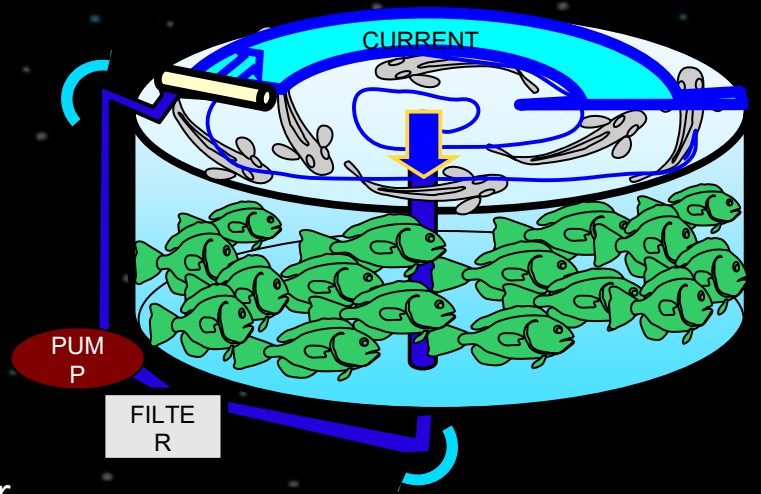
Key Mass Flows: Vegan Options

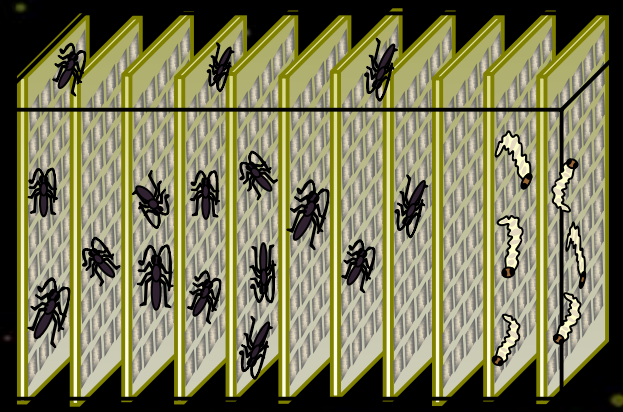


Core Technologies: Animals

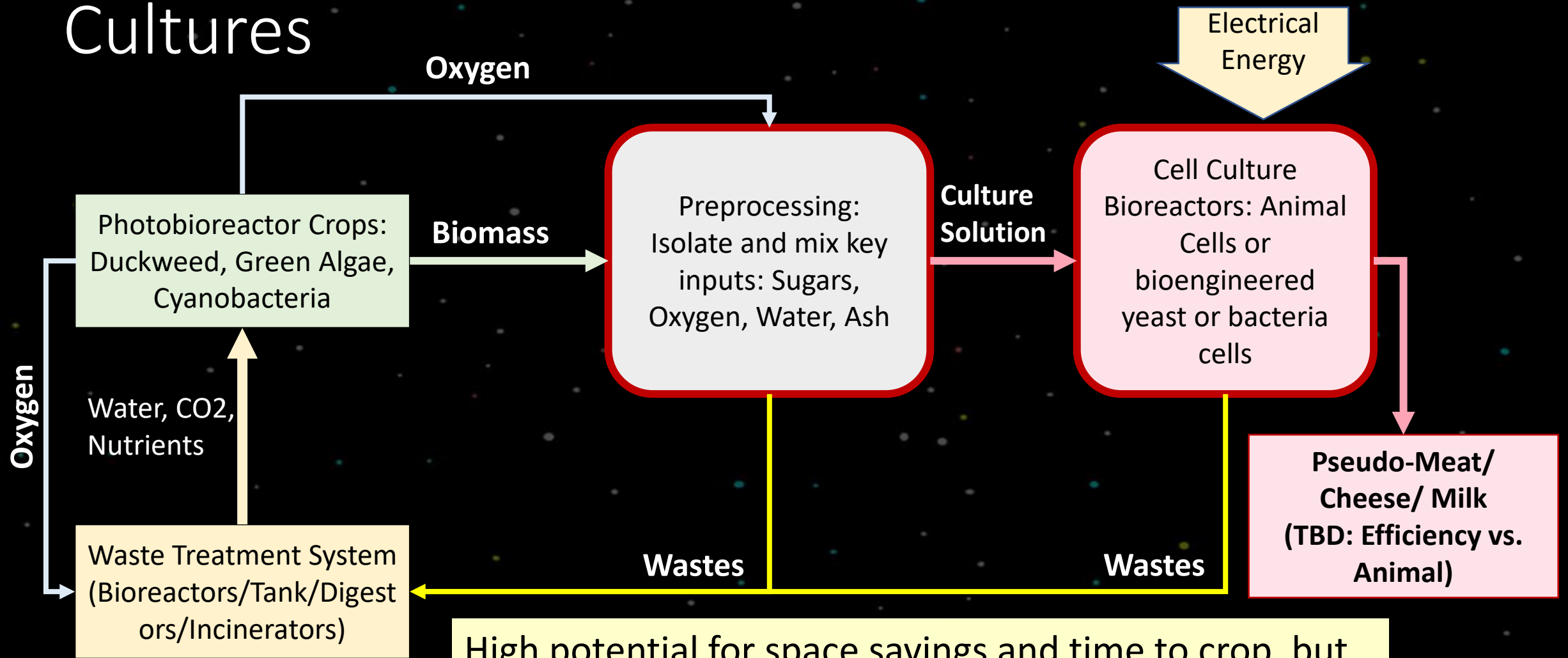
- Even if uneaten (i.e. pets):
  - Partially recycle nutrients and plant/food wastes, output can be used for Hydroponics
  - Add CO2 to cycle for plants
- If Eaten:
  - High density protein source (i.e. high protein per kcal)
  - Dietary variety
- Core Tech for small settlements:
  - Aquaculture: High density tilapia, shrimp
    - Requires water, most of stage can be built in-situ
    - Round tanks are best for small populations, raceways for larger settlements. Raceways can be set up with hydroponic beds.
    - Ship frozen gametes, Extra area for breeders
    - Species: Must eat algae and plant wastes, freshwater species first.
      - i.e. tilapia, silver carp, prawns, etc.
  - Insect-culture: Mealworms, crickets
    - Very Small initial mass, though requires gas processing
      - Fans and filters, due to high ammonia/methane

Note: 50kg of fish/ shrimp/ mollusk per cubic meter of water (max.), twice that for breeders or aggressive species





Technology Maybe: Direct Assembly and Cell Cultures



High potential for space savings and time to crop, but risks include fragility of cell cultures, and energy

Meats

This is why most Ketos are carnivores ….

yes, molluscs have some carbs…

			Dry Mass Components					
Crop (raw)	**% water**	**Kcal/kg (wet)**	**Proteins**	**Fats**	**Carbs***	**Fiber**	**Ash**	**(Fat+P+F+A)/C**
Tilapia	77%	960	86%	7%	0%	0%	6%	*(0 carbs)*
(Silver) Carp	76%	1270	71%	23%	0%	0%	6%	*(0 carbs)*
Chicken (meat+skin)	65%	3190	54%	44%	0%	0%	2%	*(0 carbs)*
Shrimp (meat)	78%	850	92%	2%	0%	0%	6%	*(0 carbs)*
Rabbits-meat	73%	1360	76%	21%	0%	0%	3%	*(0 carbs)*
Chicken-egg	76%	1430	53%	40%	3%	0%	4%	*32*
Crickets (Gryllus)	73%	1375	56%	22%	8%	8%*	6%	*12*
Mealworms	68%	1520	53%	35%	9%	0%	3%	*11*
Asian Clam (meat)	79%	860	61%	12%	19%	0%	8%	*4*
KETO ideal			**> 24%**	**> 54%**	**< 13%**	**> 9%**		**> 7**

A few day options: Seafoods and Insects Keto (2000 kcal), (Fat+P+F+A)/C =7+/-, w/nutritional mins

Crop Diversity drives farm size up

Seafood, Kosher

Crop	Grams included
Algae Oil	60
Lettuce (Arugula)	160
Bell Peppers	40
Pinto Beans	60
Quinoa	60
Oyster Mushrooms	60
Kimchi/ Saurkraut	50
Tilapia	1000

Seafood, variety

Crop	Grams included
Soybean Sprouts	10
Algae Oil	65
Lettuce (Arugula)	160
Cabbage	100
Bell Peppers	30
Pinto Beans	60
Quinoa	20
Oyster Mushrooms	50
Kimchi	20
(Silver) Carp	500
Shrimp (meat)	500
Asian Clam (meat)	10

Insects and Duckweed

Crop	Grams included
Algae Oil	50
Duckweed	50
Oyster Mushrooms	20
Crickets (Gryllus)	550
Mealworms	450

A few day options: Land Animal Options Keto (2000 kcal+/-), (Fat+P+F+A)/C =7+/-, w/nutritional mins

Chickens-Kosher

Crop	Grams included
Soybean/Algae/etc. Oil	55
Lettuce (Arugula)	200
Cabbage	100
Bell Peppers	20
Oyster Mushrooms	20
Chicken (meat+skin)	350
Chicken-egg	224

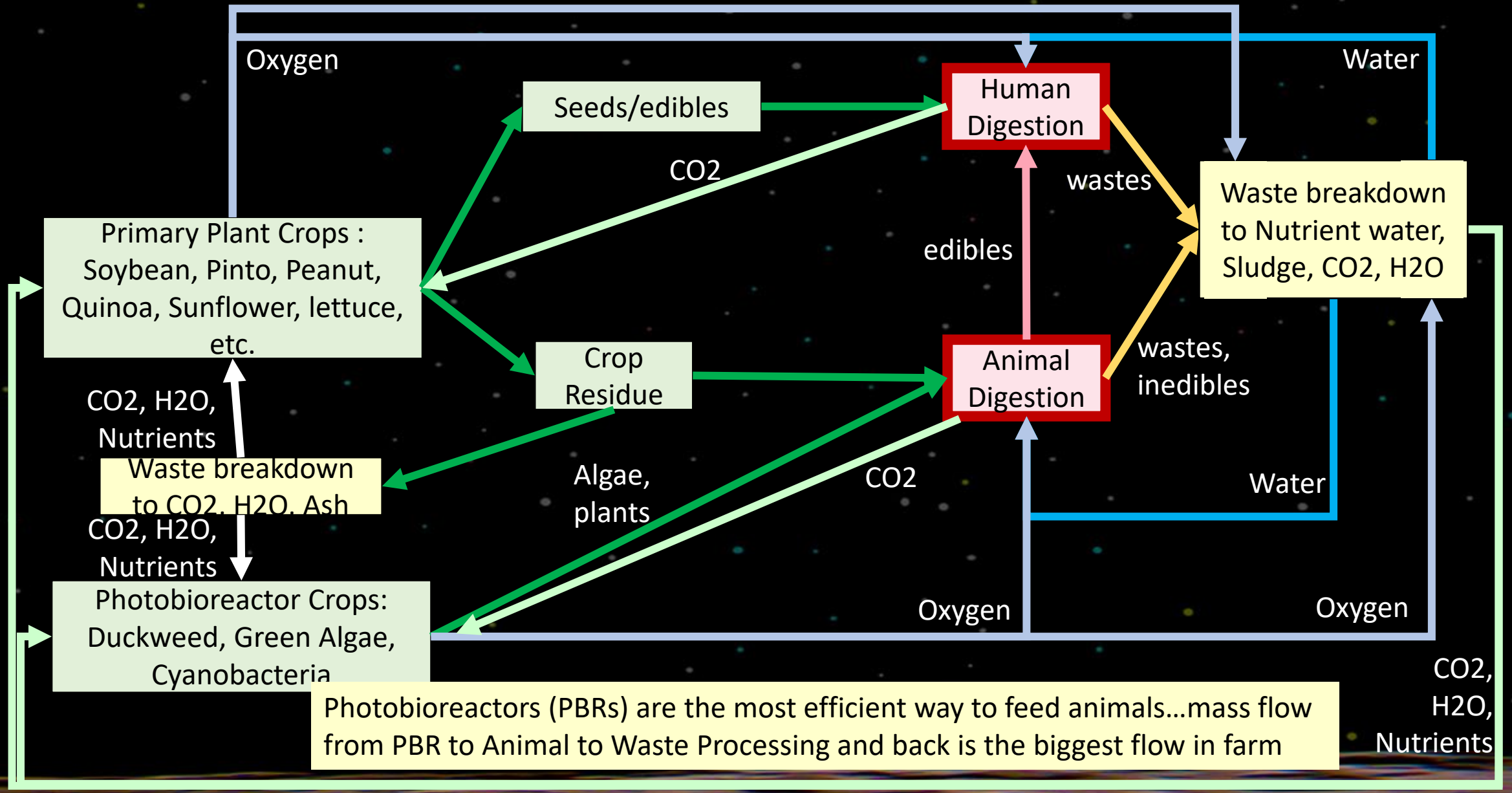
Rabbits

Crop	Grams included
Soybean/Algae/etc. Oil	70
Lettuce (Arugula)	100
Cabbage	200
Bell Peppers	30
Pinto Beans	30
Shiitake Mushrooms	50
Rabbits-meat	865

Variety

Crop	Grams included
Peanuts (Raw)	10
Soybean/Algae/etc. Oil	60
Duckweed	30
Lettuce (Arugula)	150
Cabbage	100
Bell Peppers	10
Rice	20
Kimchi	30
Chicken (meat+skin)	200
Shrimp (meat)	200
Chicken-egg	224
Asian Clam (meat)	100

Animal Feed Loop

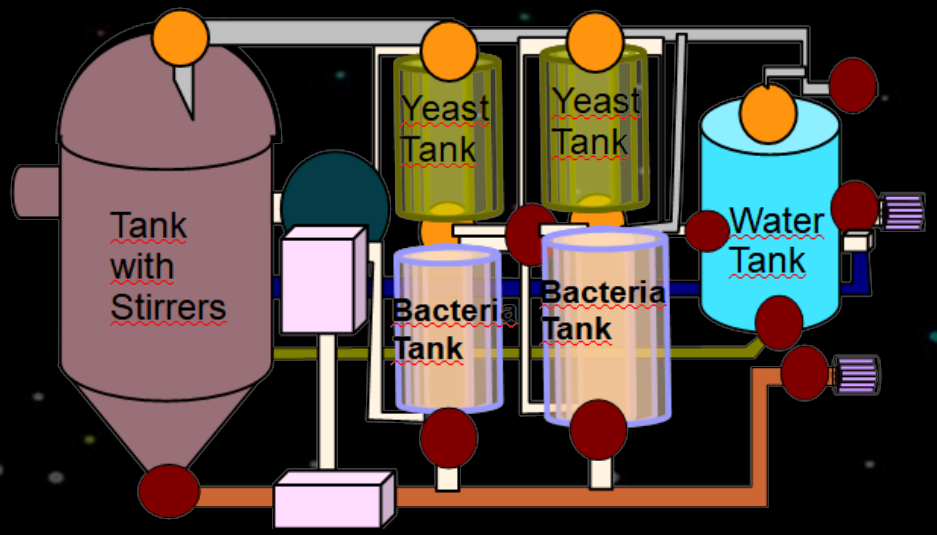


Photobioreactors (PBRs) are the most efficient way to feed animals…mass flow from PBR to Animal to Waste Processing and back is the biggest flow in farm

Core Technologies: Bioreactors and Carbon Harvesters

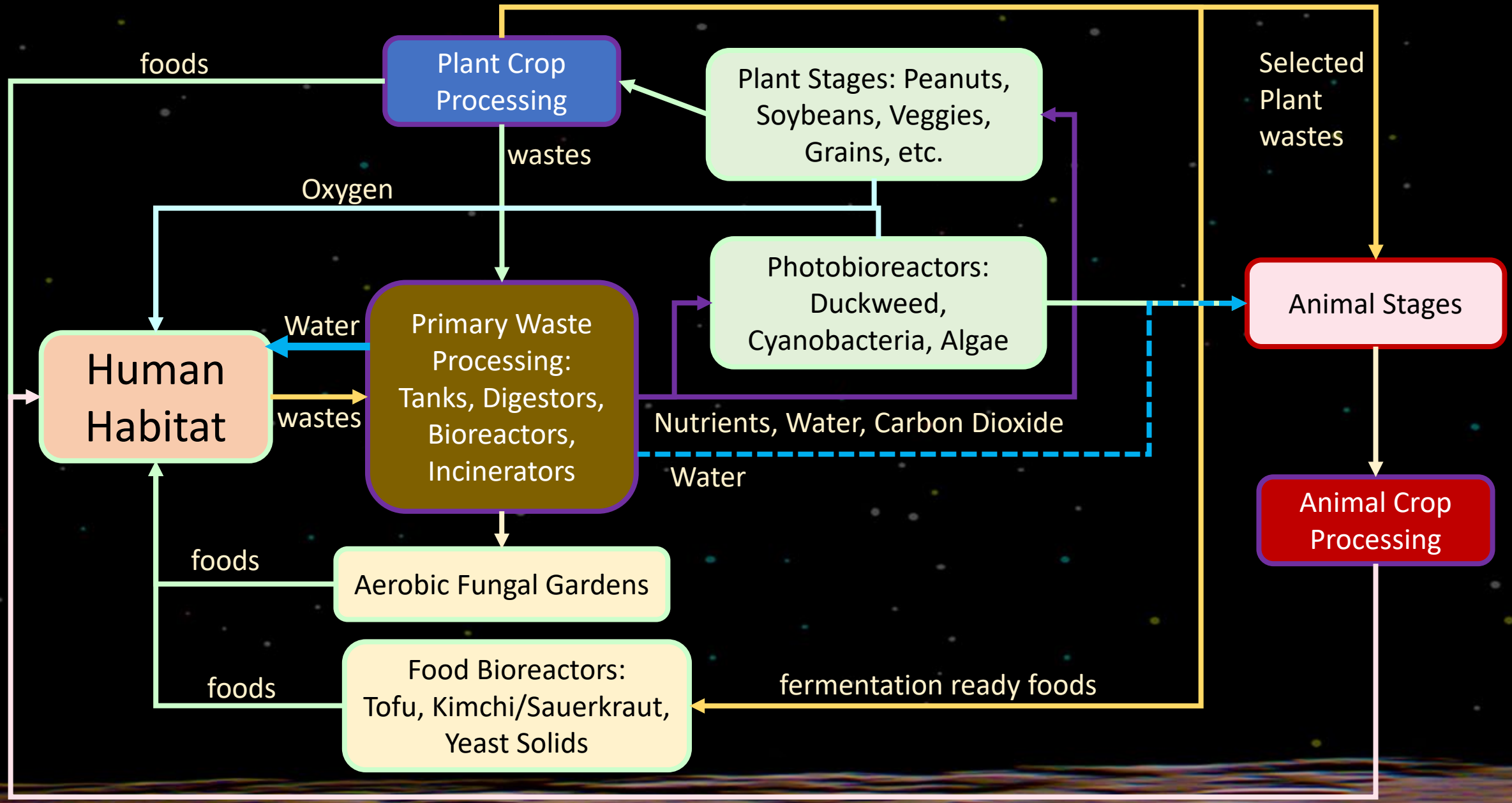
- Most biomass produced from plants is inedible matter (cellulose, etc.)
- Humans pass through most of the mass consumed.
- Carbon, Hydrogen, Nitrogen are locked in wastes.
  - Need CO_2 and H_2O to close the mass cycle.
- Earth: bacteria and fungi do most of the breakdown, followed by wildfire.
- So to get Carbon Dioxide:
  - Fermentation: Membrane based and open tank. Duplicates cow stomachs and soil.
  - Combustion: Oxygen or anoxic controlled burn to minimize undesirable products
  - Other Chemical Cycles: direct enzyme digestion/oxidation, and others.
- Of course, on Mars, CO_2 is plentiful, but on the Moon or especially in free-space, carbon is not as plentiful and must be resupplied or recycled.

Can be a simple vat as used for beer or wine, or complex like the design below:

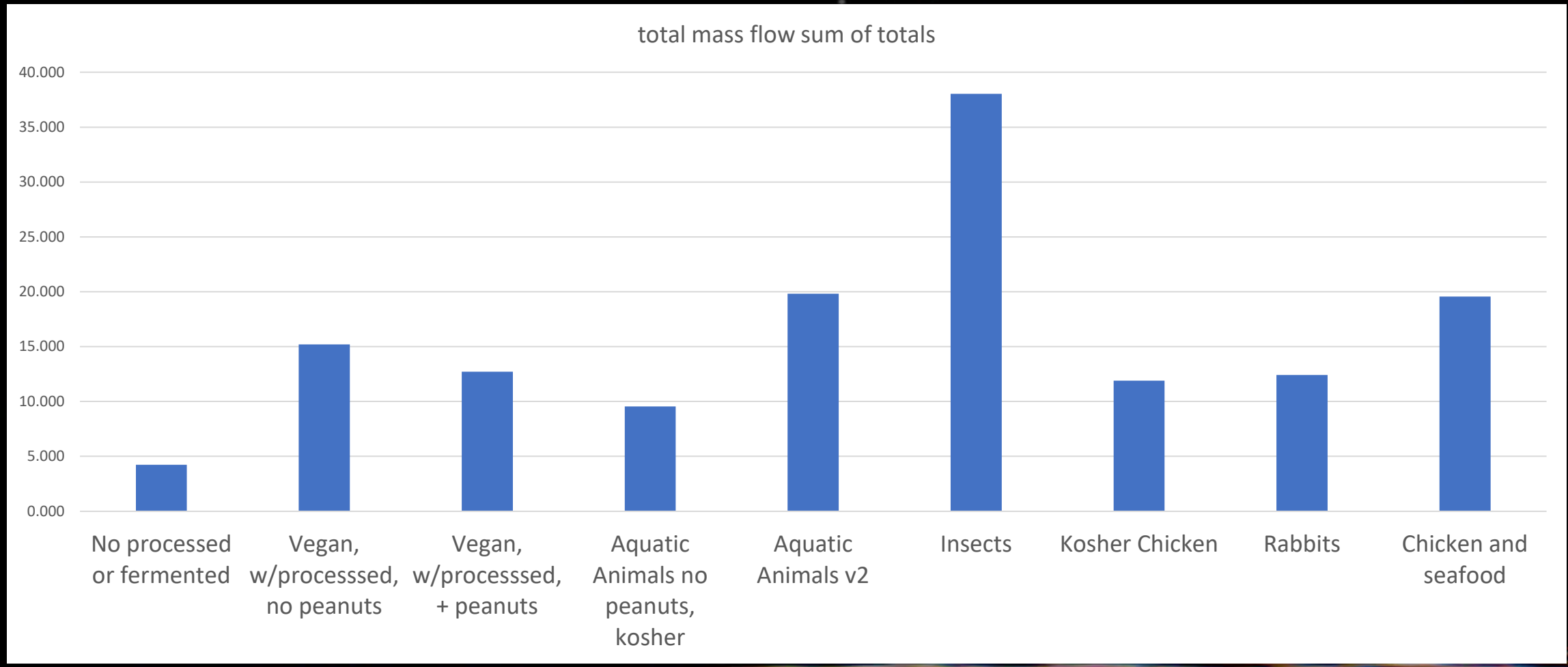


Can also produce high protein foods (i.e. yeast, lees) with even a simple vat fermenter.

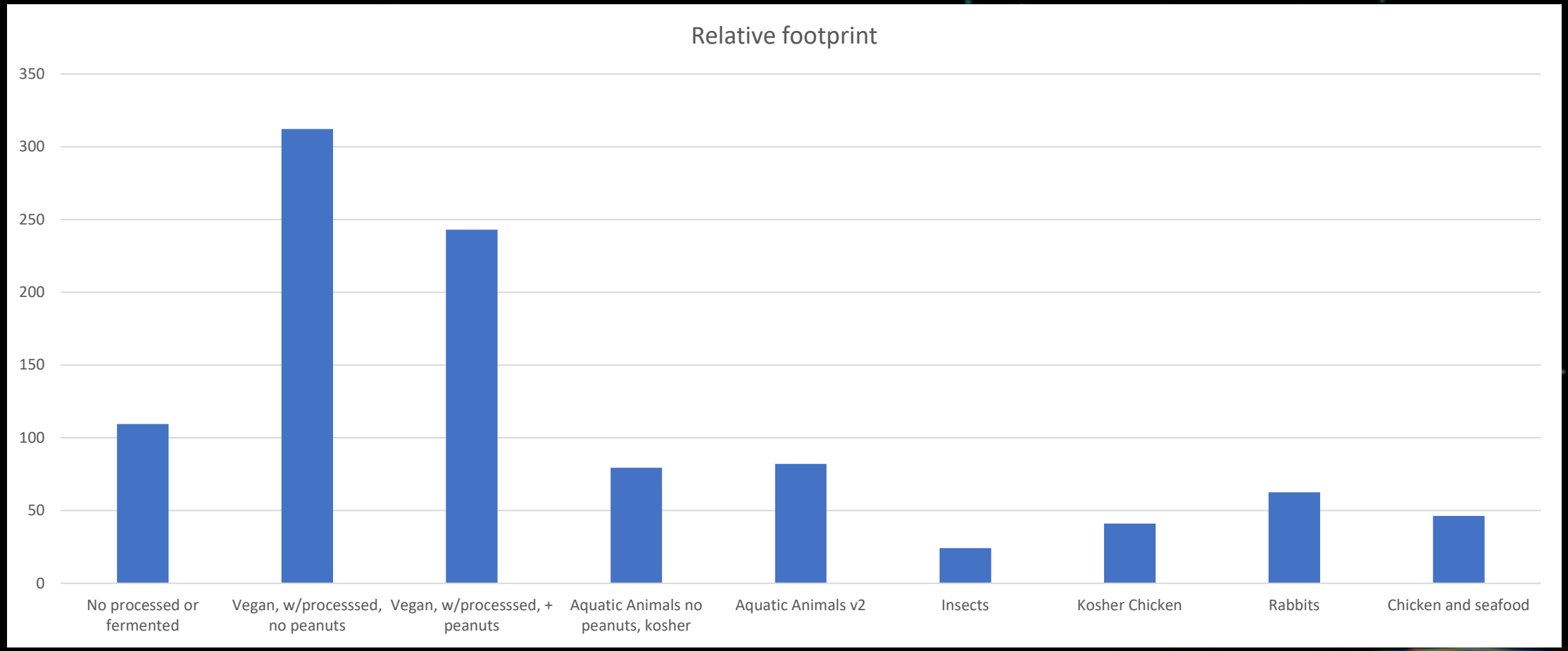
Key Mass Flows: All animal options



Crop based mass flow sums, kg/day/per person (w/o added feed algae or waste processing)



Relative Footprint (Area covered, assume> 3 m tall) (Assumes PBR+ plant waste fed animals)



Conclusion

- You can eat keto in a 3yr old space settlement!
  - Vegan
  - Meat Options
- Like all space farms, diversity drives size.
- Nitrogen inputs are very important…interesting for Moon, Mars
- Oil concentration processing via algae key to getting enough fat if peanuts or sunflowers are not on the menu. Algae is more size efficient due to doubling time and Photobioreactor size
- Major Mass flow in farms are INSIDE farm, between waste processing to and from crops

References

- https://fdc.nal.usda.gov/
- https://en.wikipedia.org/wiki/Algae_fuel
- https://www.usda.gov/sites/default/files/documents/Duckweed_Fact sheet.pdf
- https://www.sciencedirect.com/science/article/abs/pii/S0308814616313565
- https://www.researchgate.net/publication/317788034_Functions_of_Duckweed_as_a_Natural_Water_Purifying_Agent_and_as_a_Feed_Source_for_Laying_Hens
- and my upcoming book ☺

BACKUP