Introduction to Aquaponics

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Definition

- Aquaponics – Aquaculture + Hydroponics
- Basic idea is:
  - Multiple uses of water
  - Recover as much **value** from inputs as possible
  - **Minimize** negative environmental impact
  - Sustainable system

Who can/should do aquaponics?

- Backyard hobbyists
- Community groups?
- Commercial scale?
  - Fish producers who want to diversify
  - Usually shouldn't go the other way

The AU approach

- We are trying to design and operate a commercial-scale system.
- Primary process is tilapia production using biofloc technology.
- De-coupled system
- Multiple vegetable species (other plants as well)

What are we growing in aquaponics?

- What are you growing in an aquaponic system?

- *At least* 3 things:

1. Aquatic animals (usually fish)
2. Plants (high value)
3. Bacteria

Fish

- Various types of fish can be used, but we are typically limited in our selection.

1. Need a warm water species (typically).
   1. Rainbow trout (13-15 C; 55-60 F); Nile tilapia (21-29 C; 70-85 F)
2. Needs to be able to survive well in RAS.
   1. Confinement, high levels of nutrients in water, etc..
3. Needs to eat a high protein diet.
   1. Protein = N

Nile Tilapia

- Work nicely in most aquaponic systems

- Tilapia are tough fish.
  - Tolerate wide range of pH
  - Tolerate high concentration of nitrates
  - Vigorous eaters
  - Eat primary feed and partially digested feed

- Adaptive to many environments.

- Value?

Plants

- Need to grow high-value plants.

- Species that are normally grown in hydroponics.

1. Lettuce
2. Cucumbers
3. Peppers
4. Tomatoes

- With some exceptions possibly…

Bacteria

- Two major types of bacteria are crucial to success in aquaponics:

- *Nitrosomonas* spp.
- *Nitrobacter* spp.

- Both types must be present to effectively transform waste into fertilizer.

How does it work?

- The science behind aquaponics relies on an understanding of the nitrogen cycle.
- In natural systems, nitrogen is cycled from one form to another to another, and so on…
- Aquaponics utilizes this natural cycle to produce protein and vegetables in the same system.

The Basic Idea

1. Fish convert protein (organic N) into ammoniacal-N excreted in feces, urine, and through gills.
2. Bacteria convert ammoniacal-N to nitrate-N.
3. Plants remove nitrate-N from water.

System Design Options

- Continual recirculation (circular design)
  - Fish – plants – fish – plants
- De-coupled system (linear design)
  - Fish – plants – plants – plants

System schematics

- **Primary process** is fish production in any aquaponic system.
- Either the fish are being intensively produced for sale, utilized as fertilizer factories, or both.
- Re-tasking the fish waste leads to the secondary and tertiary processes.

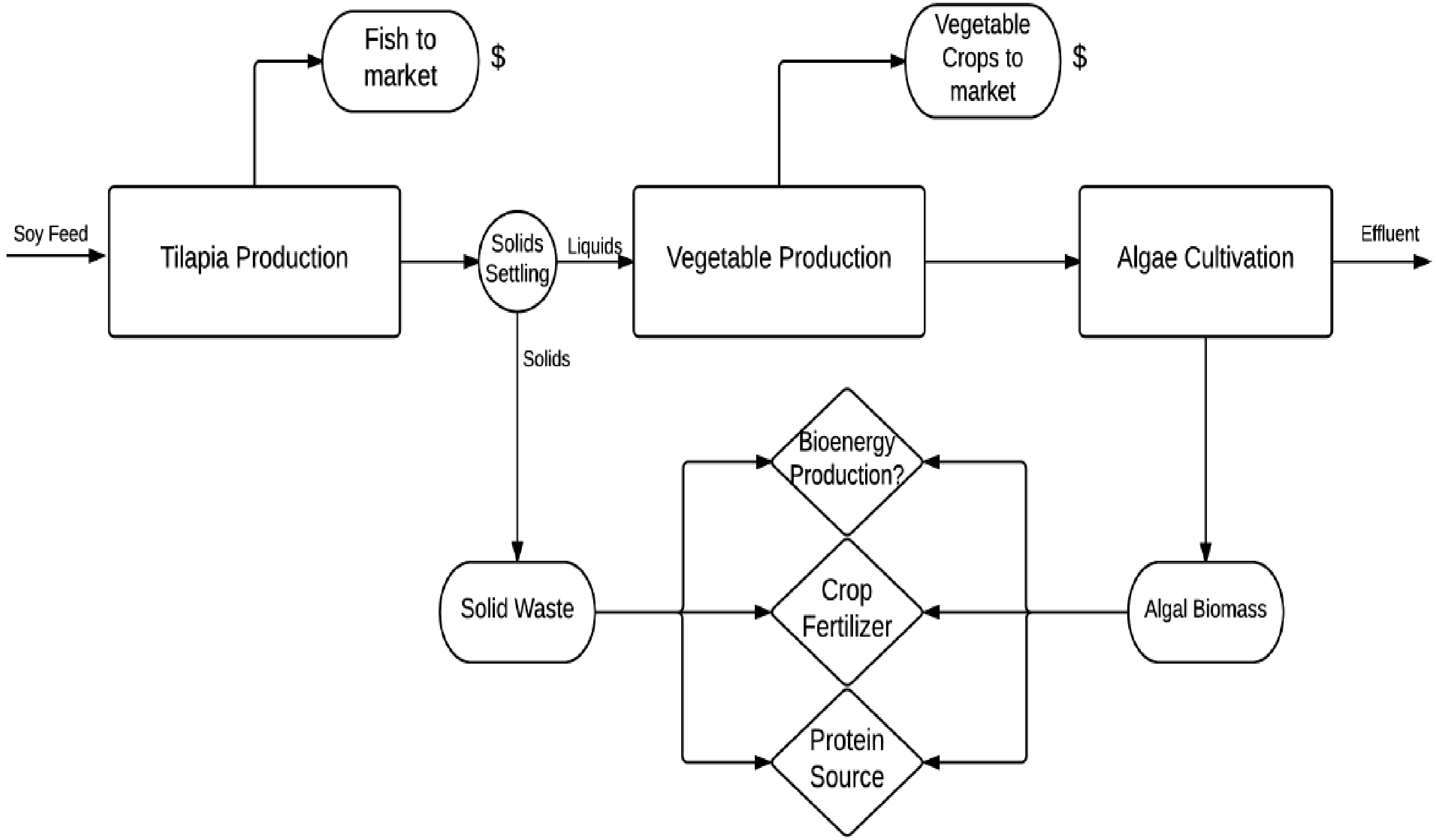
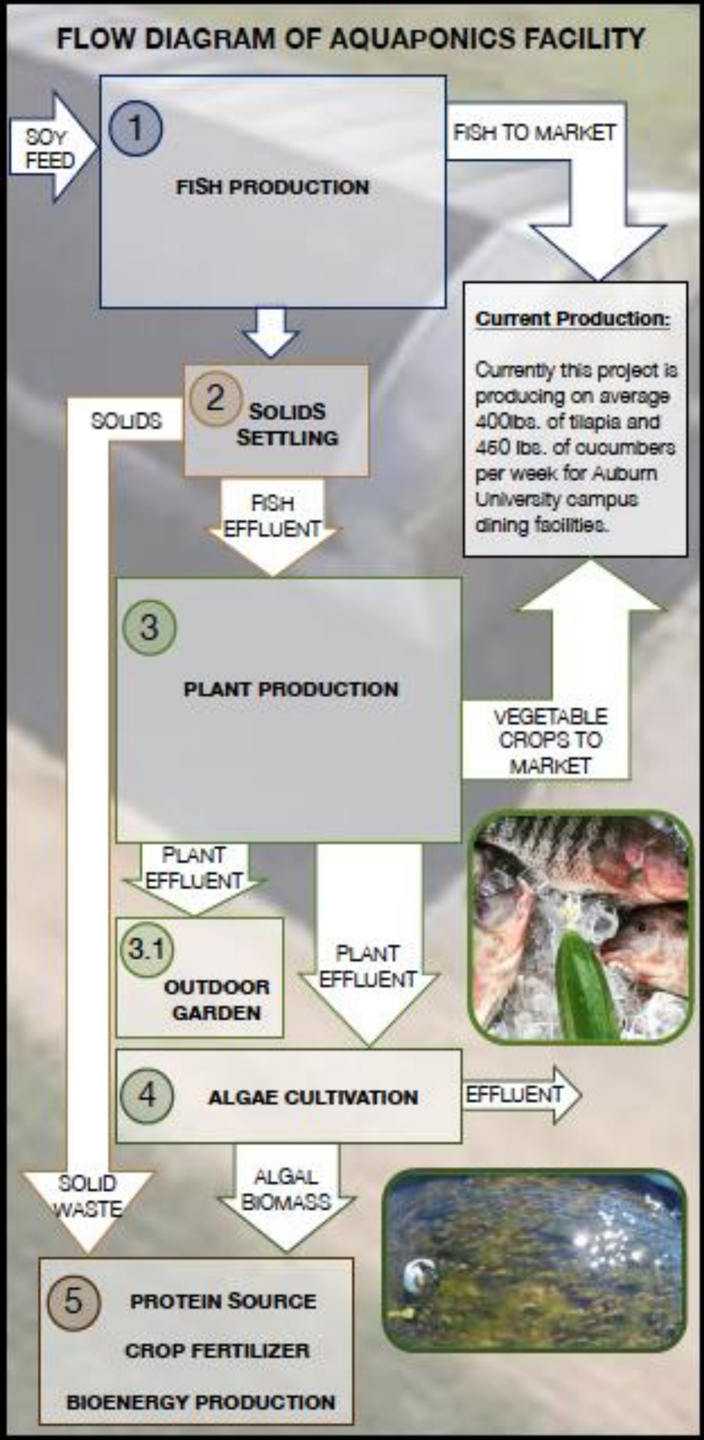


Figure 2: *Systems schematic of the Auburn University aquaponics facility*



- High-protein, soy-based feed and water are the primary inputs into the system.
- Track the water movement through the system.
- Nutrients (N) move with water through the system.
- Multi-use water and nutrients.

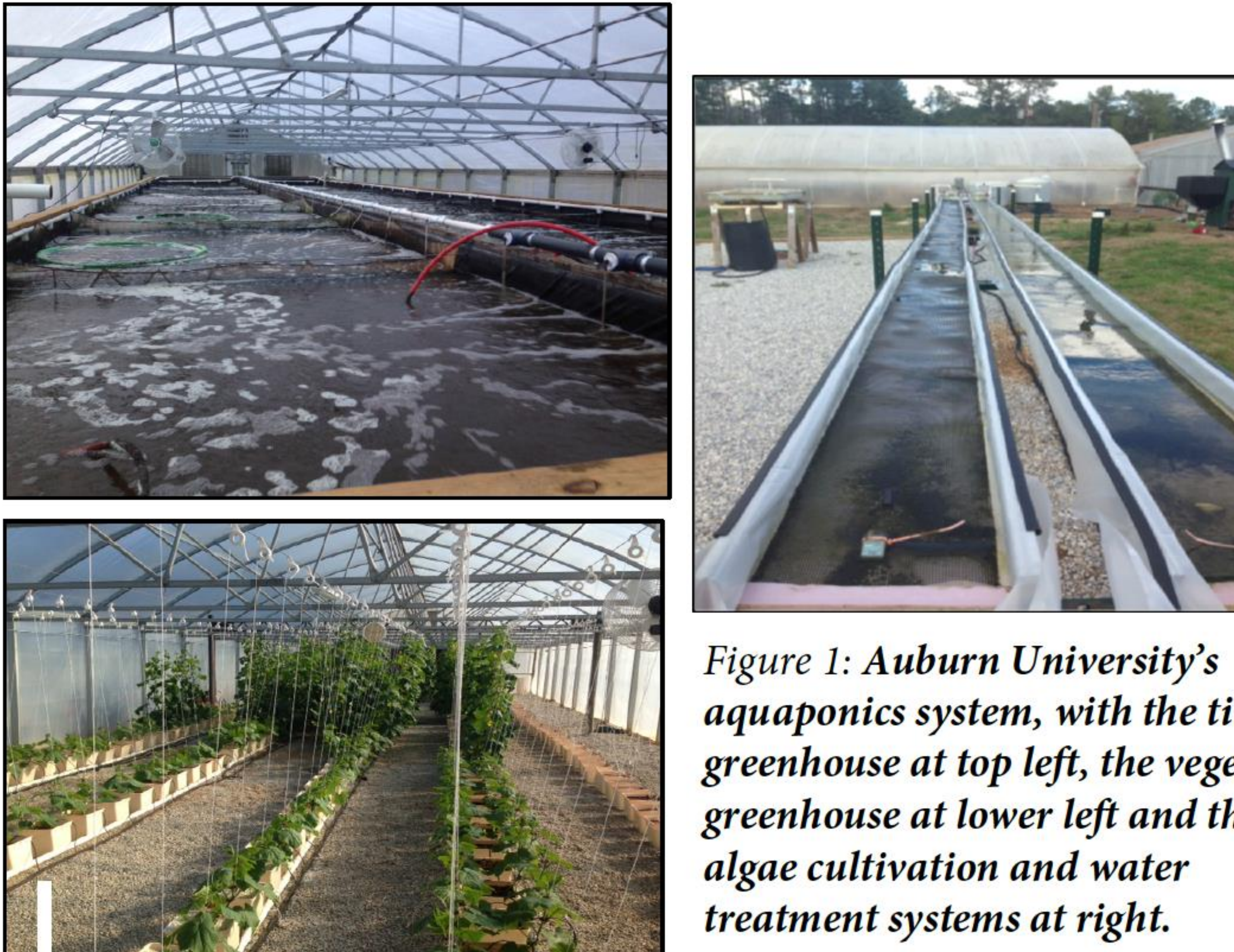
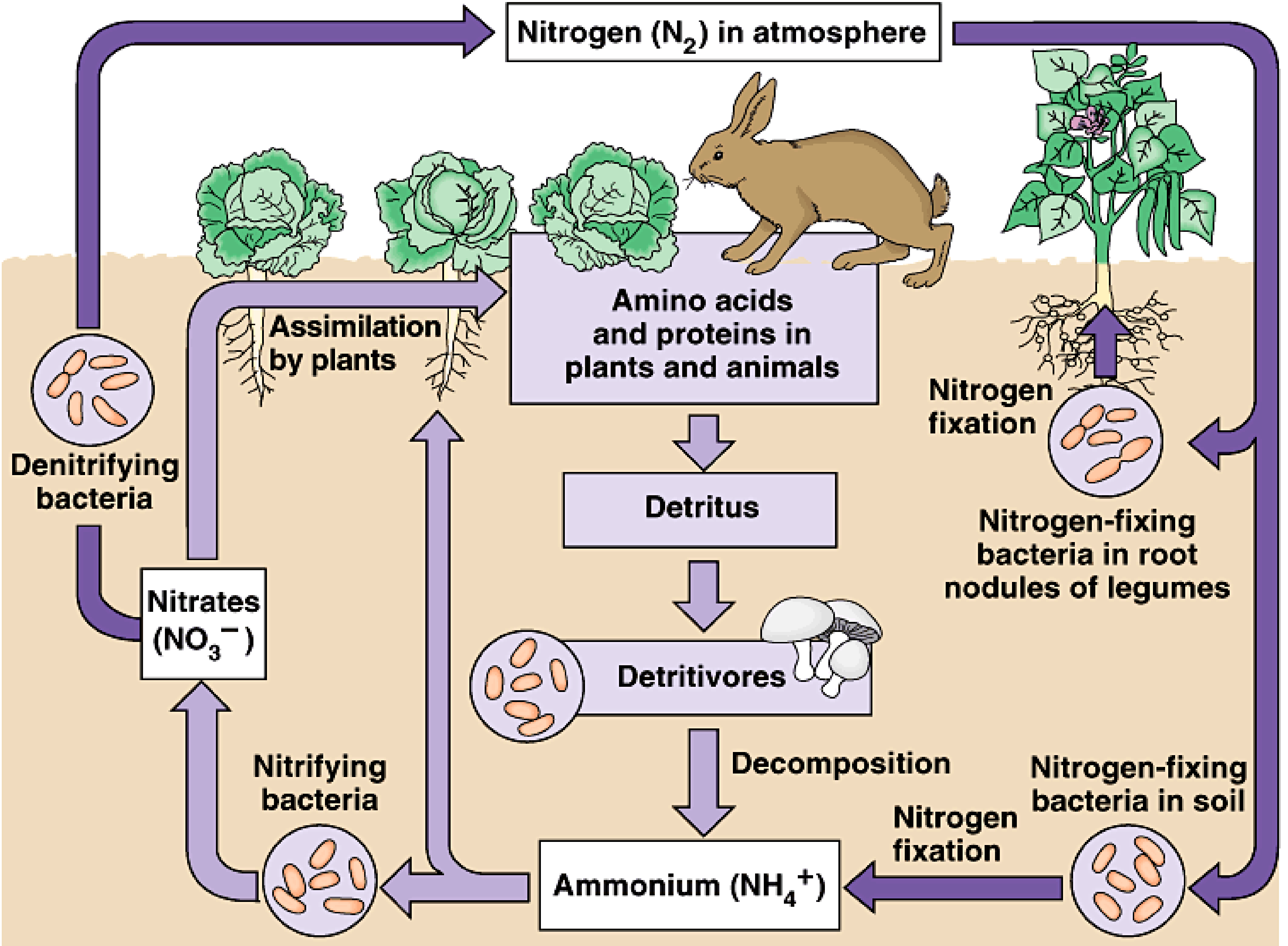


Figure 1: ***Auburn University's aquaponics system, with the tilapia greenhouse at top left, the vegetable greenhouse at lower left and the algae cultivation and water treatment systems at right.***

University of the Virgin Islands (UVI) System

Nitrogen cycle

- Nitrogen is present in multiple forms in our environment.
- N_2 gas in atmosphere (70%)
- Organic N (amino acids, proteins, DNA, etc.)
- Ammoniacal N – Ammonium (NH_4^+) and ammonia (NH_3)
- Nitrites (NO_2^-)
- Nitrates (NO_3^-)


Nitrogen (N_2) in atmosphere
Amino acids and proteins in plants and animals
Assimilation by plants
Denitrifying bacteria
Nitrogen fixation
Nitrogen-fixing bacteria in root nodules of legumes
Detritus
Nitrates (NO_3^-)
Detritivores
Decomposition
Nitrifying bacteria
Nitrogen-fixing bacteria in soil
Nitrogen fixation
Ammonium (NH_4^+)

Bacteria are our friends

- Bacteria are the workforce behind aquaponics
- Will not work at all without bacteria
- We want to grow the right types and set up the right conditions for them to be happy
- *Nitrosomonas* spp.
- *Nitrobacter* spp.

Biofilter

- A biofilter is material that allows bacteria to colonize and do the work we want them to do.
- In this case, *nitrification*.
- Many different types of biofilters are available.
- Shredded PVC (surface area) – 3D printed media – bead filters - flocculants within fish production water

Biofilter

- For biofilters to be most effective, we need constant agitation of the water.
- The biofilter can be within the water column of the RAS or outside it.

Biofilter

- **Low-cost system that we use at AU**: Bio-floc technology (BFT)

- Water column in RAS ***is*** the biofilter.

Biofloc Technology (BFT)

- Bacteria *flocculate* together, when present in very high concentrations, to form "bioflocs"
- Bioflocs are suspended in the water column through constant aeration (bubbling)
- Bacteria in bioflocs carry out nitrification!

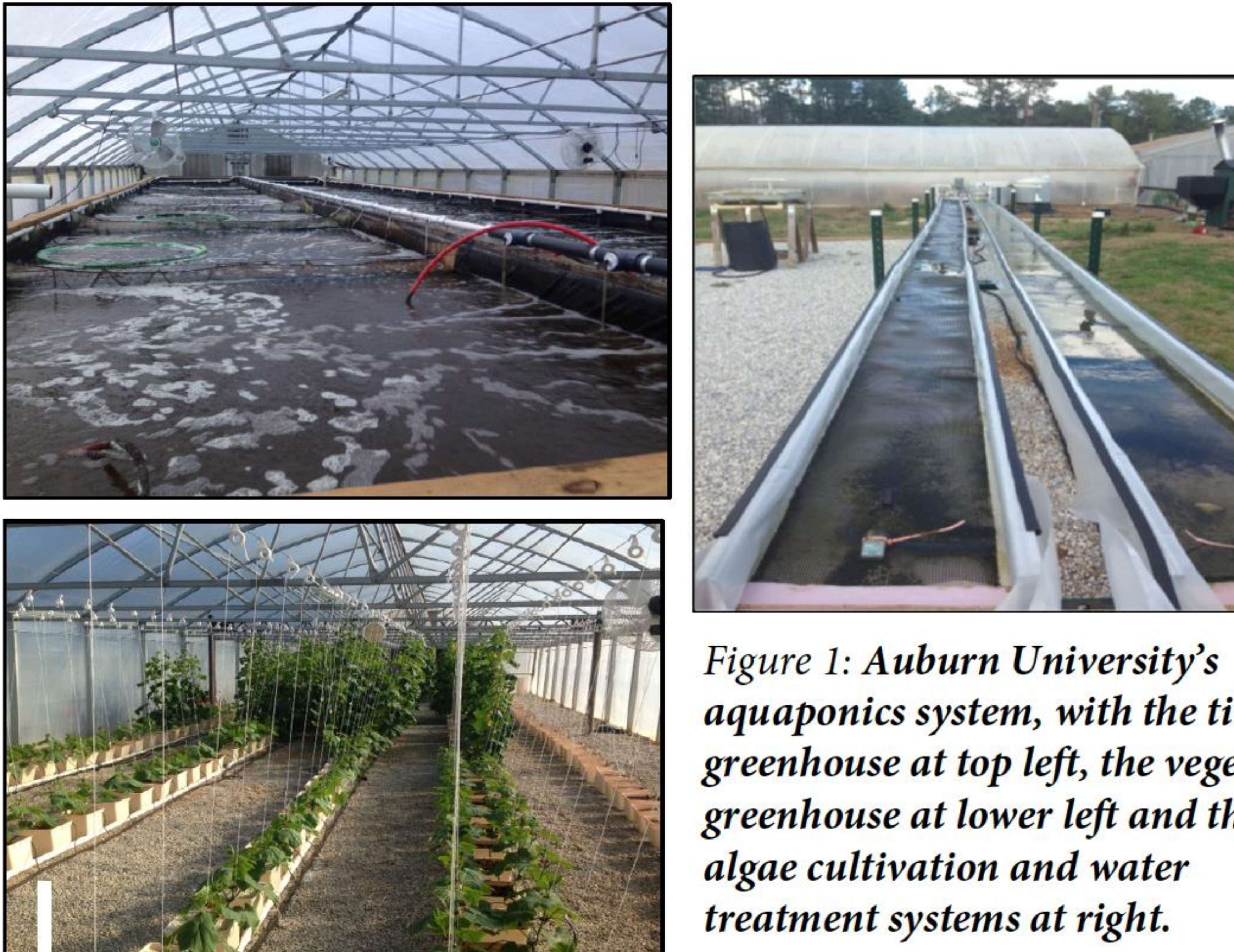


Figure 1: ***Auburn University's aquaponics system, with the tilapia greenhouse at top left, the vegetable greenhouse at lower left and the algae cultivation and water treatment systems at right.***

- So, solids in the system are constantly agitated via aeration.
- Solids = solid waste, bioflocs, partially digested waste, etc..
- Tilapia will eat primary feed and bioflocs.
- Increases FCR (Feed Conversion Ratio)!

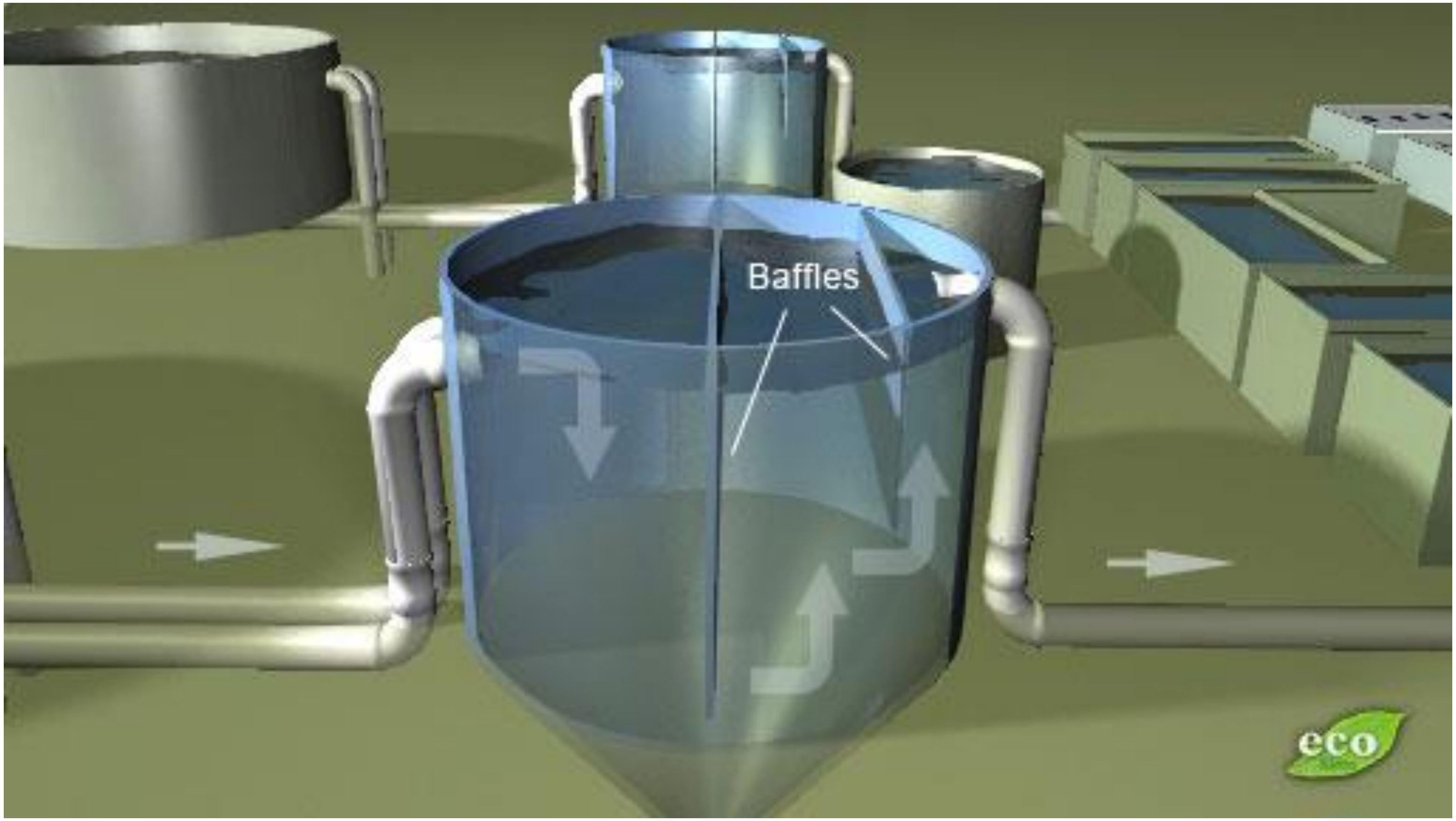
What do we do with the solids?

- We must remove the solids on a regular basis.

- Can repurpose solids –
  1. Organic soil amendment
  2. Horticultural substrate amendment
  3. Anaerobic digestion – biogas
  4. Fermentation – lactic acid production

- Liquid fraction = nitrates

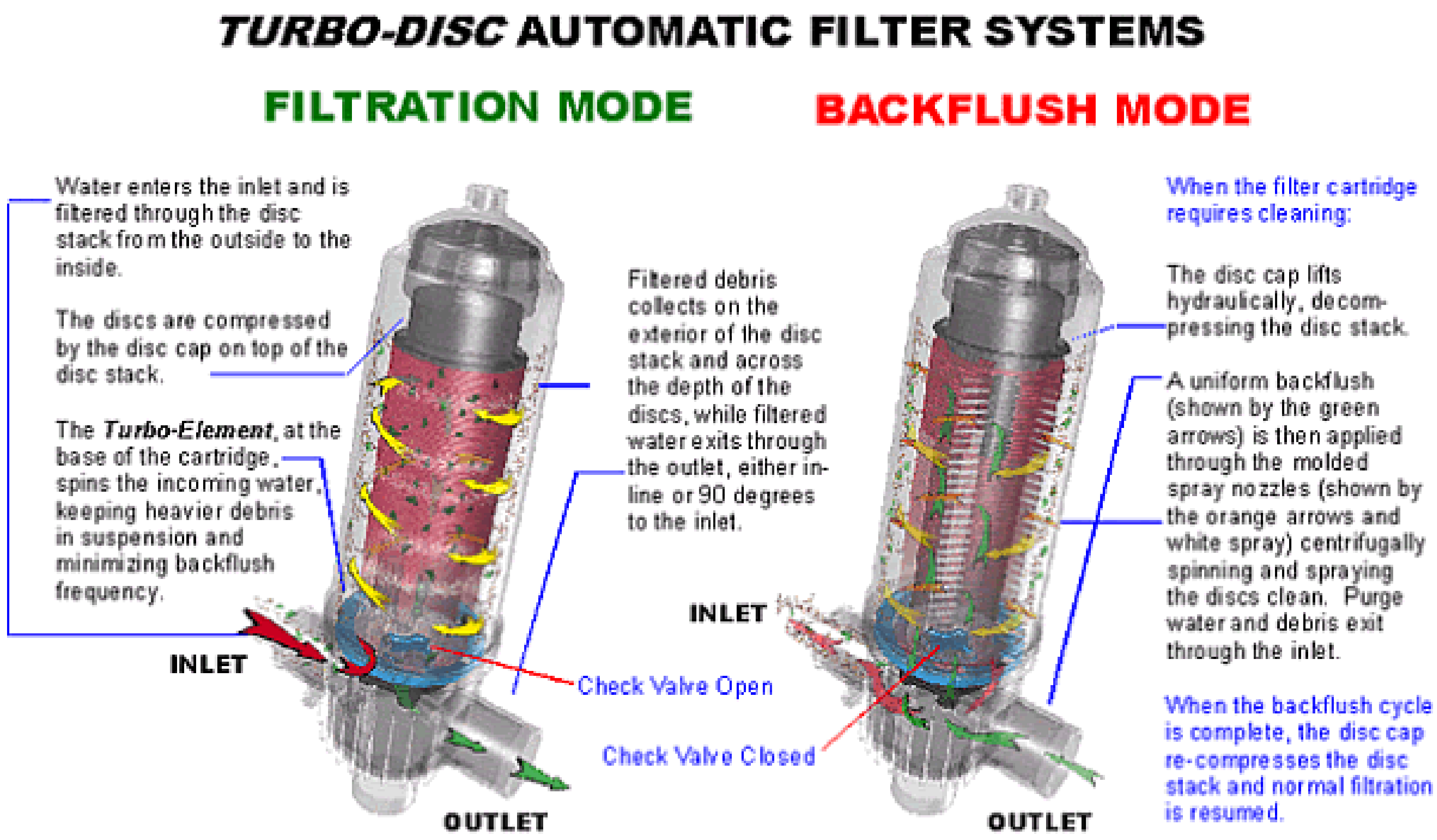
Conical Clarifier: Passive clarification



Clarified water is pumped from clarifier B using an irrigation pump

A = primary clarifier with baffle
B = secondary clarifier without baffle
C = solids removal sump

Active Filtration



Solids are Bad!

- Whether we use **water culture** or soilless culture, we can't have too many solids in our nutrient solution.

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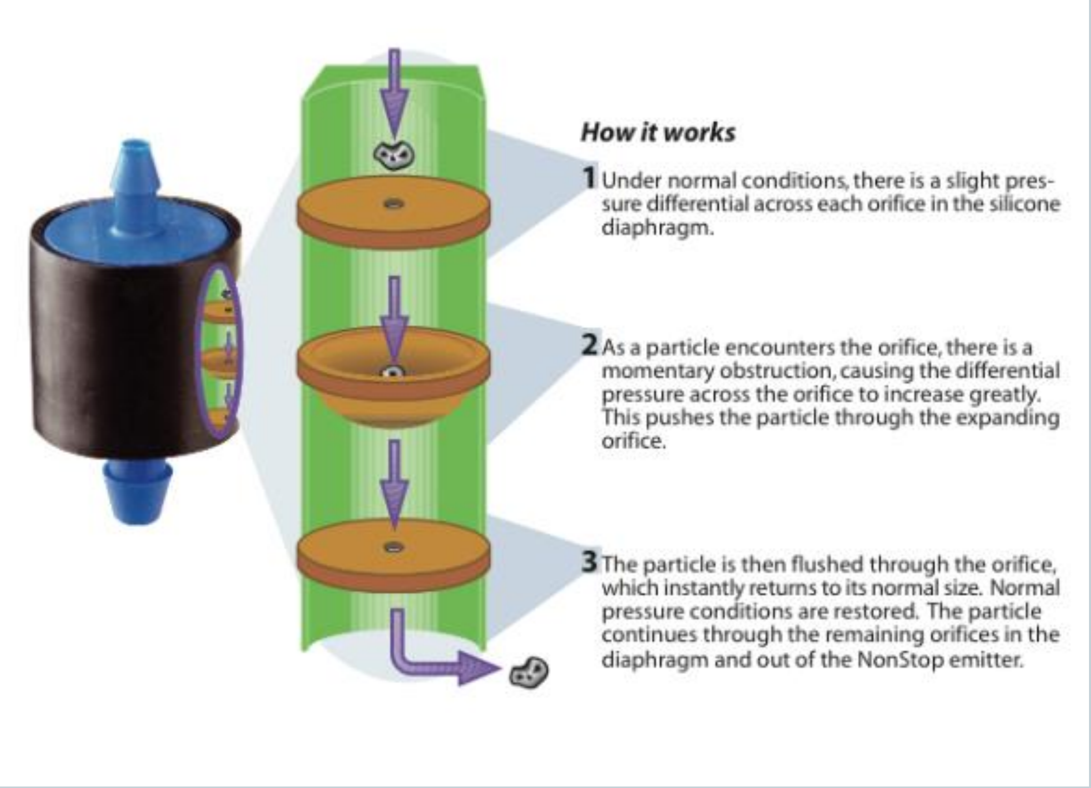
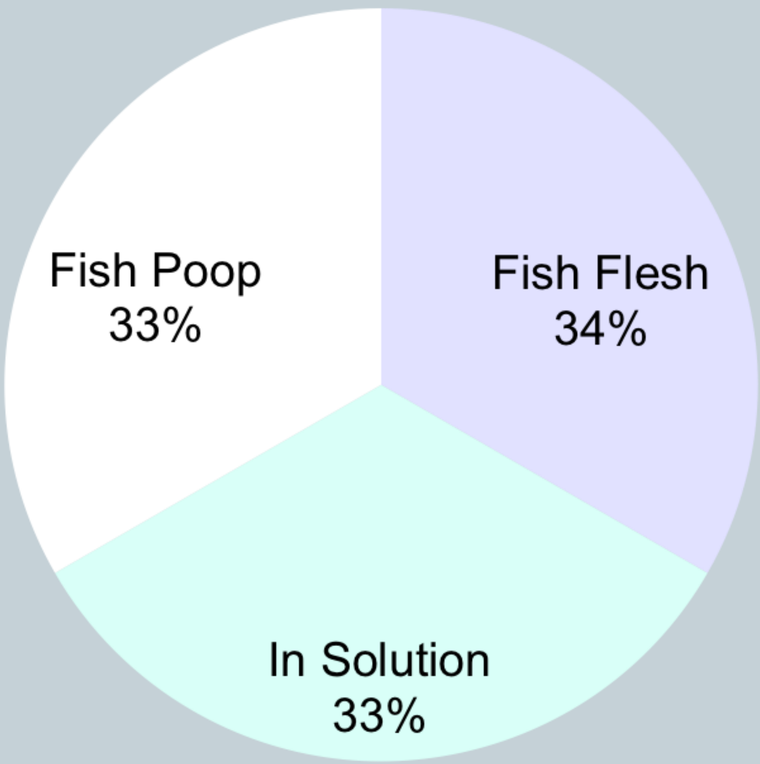


What do we have to work with?

Fertilizer analysis of fish feed and fish manure

	Fish Feed	Fish Manure
CrudeProtein_Dry	35.7%	22.8%
Nitrogen	5.7%	3.6%
Phosphorus	1.2%	0.9%
Potassium	1.5%	0.2%
Calcium	1.2%	2.0%
Magnesium	0.3%	0.2%
Sodium	0.2%	0.5%
Iron (ppm)	250	3575
Manganese (ppm)	99	544
Copper (ppm)	21	99

What happens to N when you feed fish?



NITRIFICATION

Ammonia (NH_3): Ammonium (NH_4)
TAN

Nitrosomonas

↓

Nitrite
(NO_2-)

Nitrobacter

↓

Nitrate
(NO_3-)

$NH_4^+ \rightarrow NO_3^-$

H^+ H^+ H^+

pH ↓

DENITRIFICATION

Nitrate (NO_3^-)

Nitrogen Gas (N_2-)

H_2O

H^+ H^+ H^+

pH

Nitrification

- If we want to maximize our efficiency it is in our best interest to maximize nitrification
- Much debate in aquaponics world about this
- At AU, we have taken the commercial food production approach to the problem
- Some other institutions have attempted primarily to maintain balance in the system

Nitrification

- *Nitrosomonas* spp.
- *Nitrobacter* spp.

- Most efficient (happiest?) at pH 7.5 – 8.5
- Plants are happiest at 5.8 – 6.5

- What pH do we shoot for?

- Nitrification will drive pH down!

Finding the right pH in our system

- At this point, AU aquaponics system runs at pH 6.2 – 6.8.
- Plants are happy (at least pH-wise)

- Avg. daily nitrate concentrations = 200 – 600 ppm

- 200 – 600 ppm NO_3-N = **45 – 135 ppm N**

Recommended Nutrient Concentrations
Aquaponics vs Hydroponics

Nutrient	Aquaponics (mg/L)	Hydroponics (mg/L)
Calcium	10.0 – 82.0	150.0
Magnesium	0.7 – 13.0	50.0
Potassium	0.3 – 192.0	150.0
Nitrate	**0.4 – 82.0**	**115.0**
Phosphate	0.4 – 15.0	50.0
Sulfate	0.1 – 23.0	113.0
Iron	0.03 - 4.3	5.0
Manganese	0.01-0.20	0.5
Copper	0.01-0.11	3.0
Zinc	0.11-0.80	0.05
Molybdenum	0.01-0.23	0.05
Boron	0.01-0.17	0.5

- We may get more nitrification at higher pH
- Increase plant production!
- Ultimately, we want to design a system in which all of our nitrates and water are being utilized within the system (i.e. minimal waste)
- How do we increase pH?

- Our water has low alkalinity.
- Add lime to the water.
- Hydrated lime – $Ca(OH)_2$ (very caustic, use with caution)
- Currently, we add lime weekly.
- We would need to add lime daily to maintain pH >7

Problems with high pH?

- A major problem with high pH in fish production is the higher presence of "un-ionized" ammonia
- **NH_3**
- NH_4 much less toxic to fish
- $[NH_3] > 5$ mg / L = dead fish

- In theory: higher pH = more bacteria = more nitrification = less TAN
- **What about other nutrients?**
- We supplement potassium (K), calcium (Ca), and Iron (Fe)
- Muriate of potash (K), hydrated lime (Ca), chelated iron (Sprint 330)

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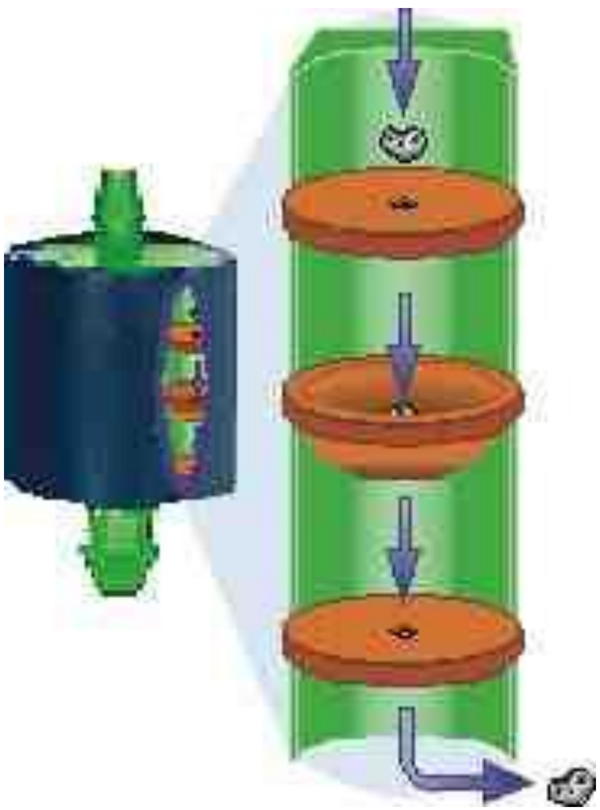
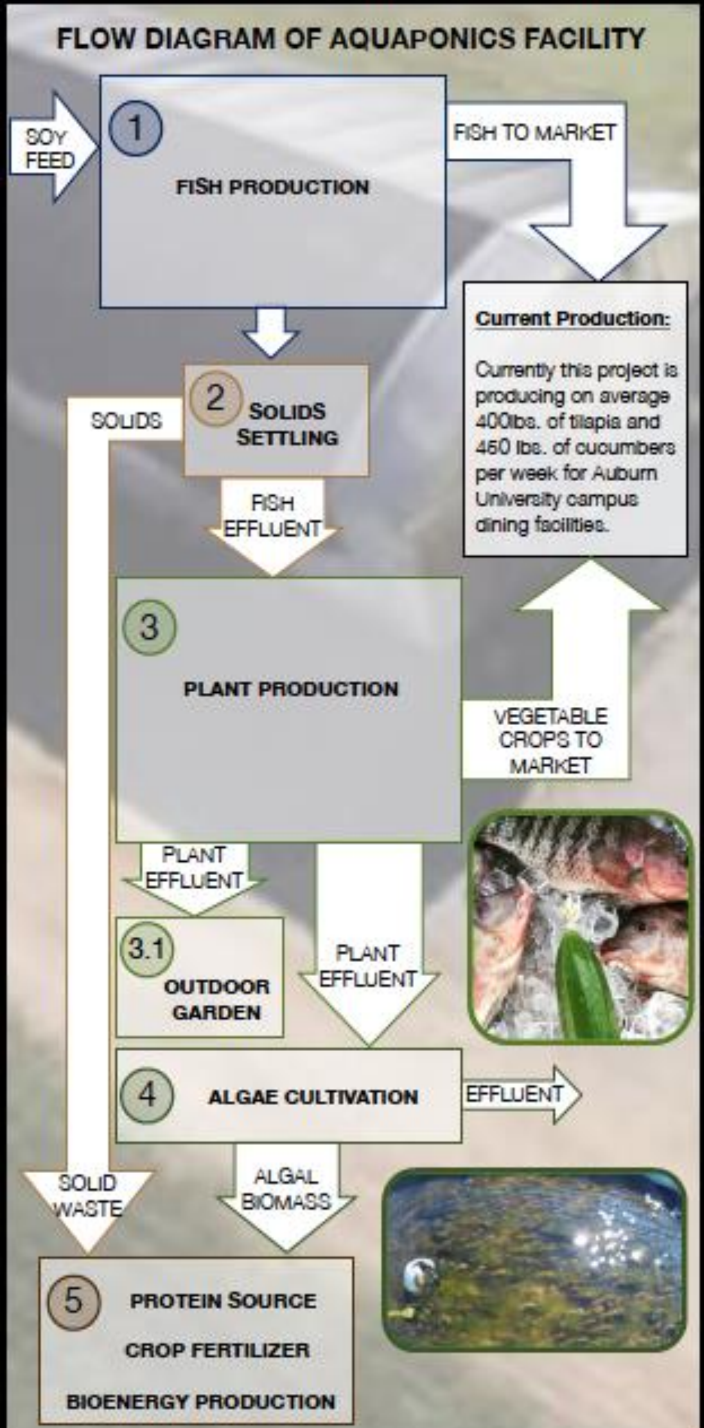
Dutch Bucket Culture / Beit Alpha Cucumbers

No-Clog Emitters (Bowsmith)



Dutch Bucket Culture / Beit Alpha Cucumbers



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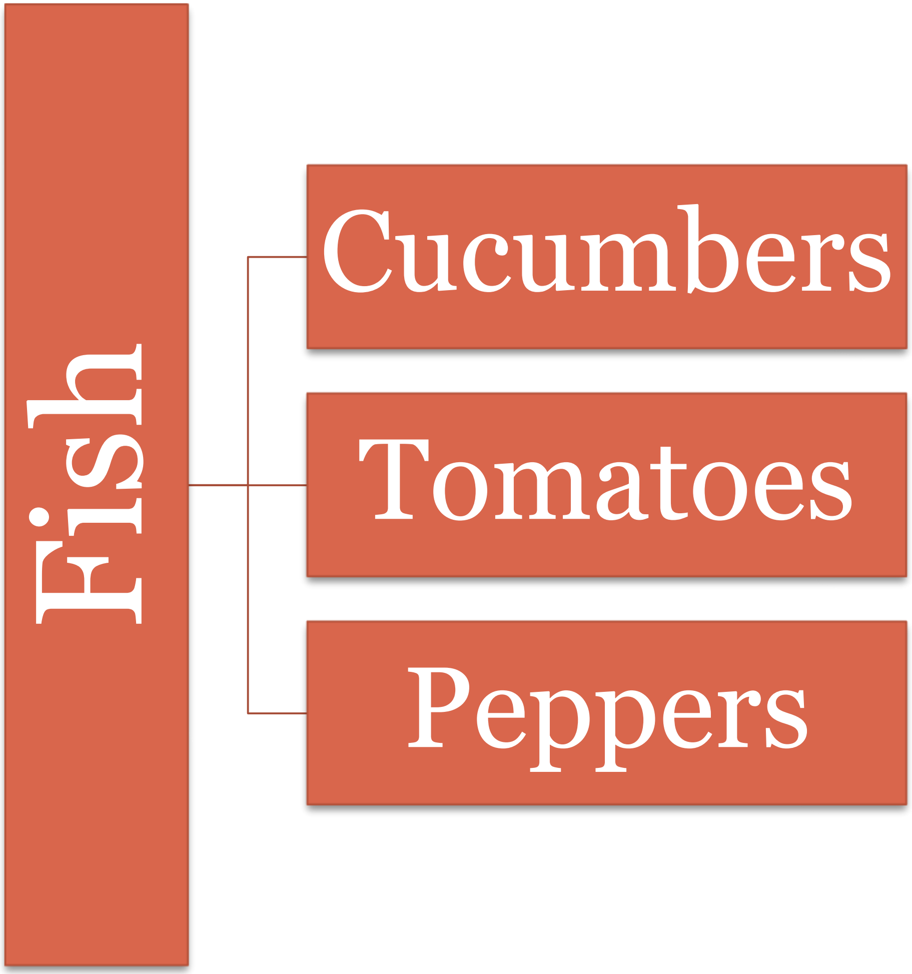
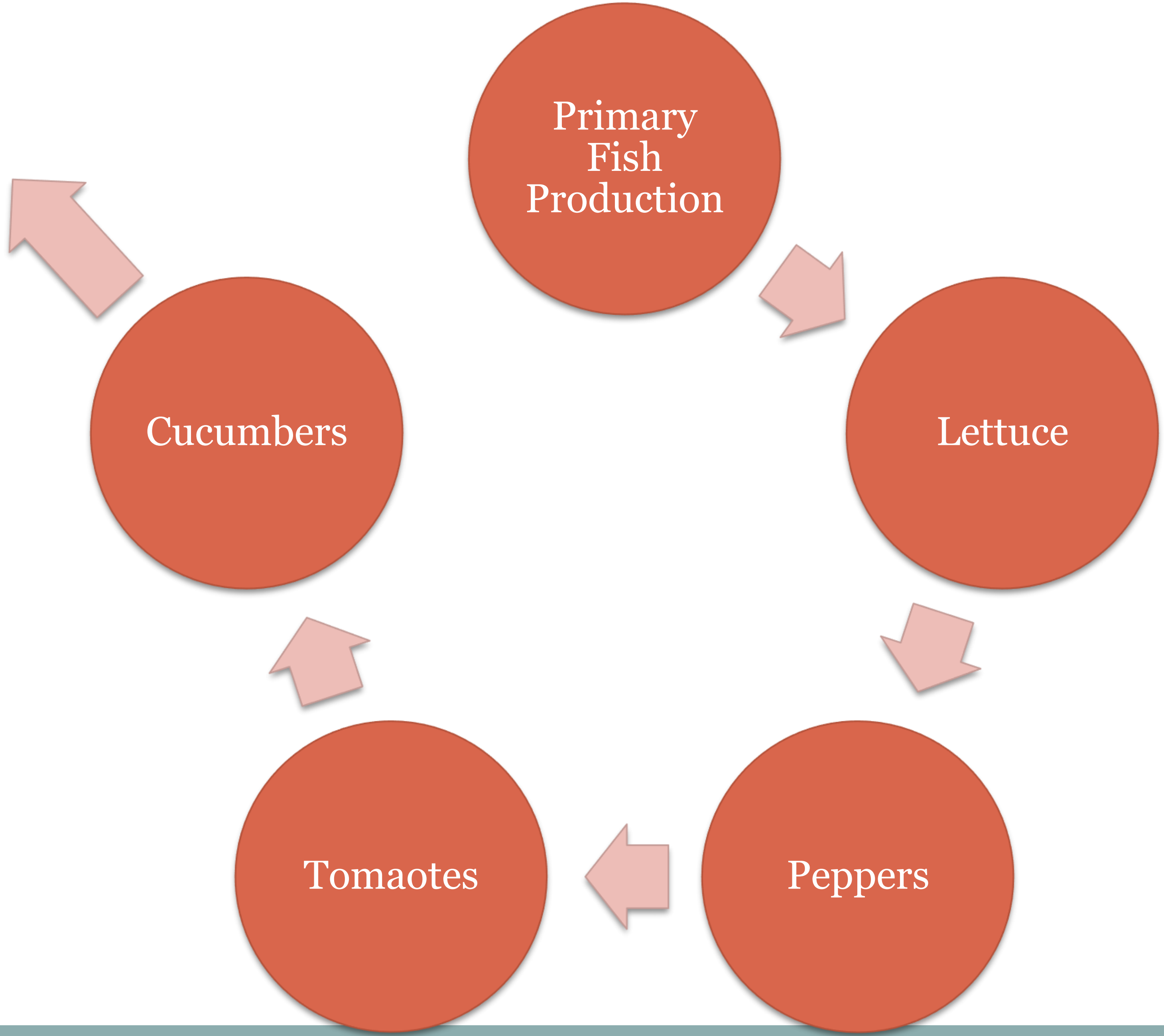
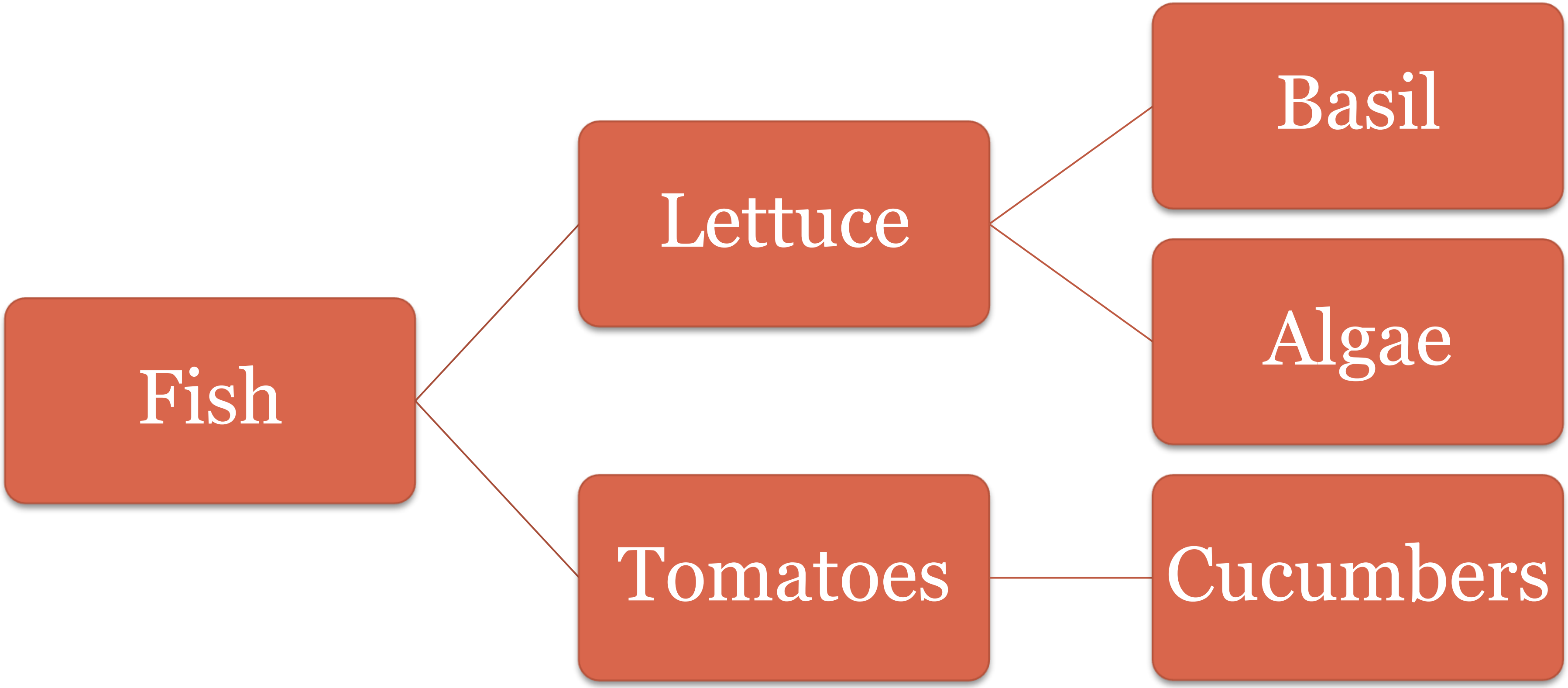

Fish
Cucumbers
Tomatoes
Peppers



Primary Fish Production
Lettuce
Peppers
Tomaotes
Cucumbers


Fish
Lettuce
Tomatoes
Basil
Algae
Cucumbers

Why decouple?

- Pesticides, even organic options, are often highly toxic to fish.
- Maximizing water use efficiency does not mean the same thing as recirculating water over and over.
- Diseases?

Is Aquaponics commercially viable?

- The technology works. Proven in several, different systems.
- Can you make $?
- Is it safe??

The Current Situation

- Intensive aquaculture (RAS) is not profitable, in many cases.
  - Low cost of imported fish
  - Expensive to process
- “You make money on the plants”
- So, why aquaponics?