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Algae Biofuels 101

How To Save Money On Gas and Heating Oil Using Algae.

Chapter Four:

Building Test Bioreactors

www.Making-Biodiesel-Books.com

Chapter Four: Introduction

The most important thing to take away from this lesson is…Photobioreactors (PBR's) DO NOT have to be difficult

Why Use a PBR?

When it comes to growing algae you have two choices in life…open ponds or PBR's.

The truth is, you'll probably need both.

Depending on your application, volume of algae needed, and climate will determine which method will work the best for you.

A photo bioreactor (PBR) can be described as an enclosed, lighted, algal culture vessel designed for controlled production of algae. Photo bioreactors, have several major advantages over open ponds, they can:

- Prevent or minimize contamination
- Offer better control over existing conditions (p_H, light, carbon dioxide, temperature).
- Prevent water evaporation,
- Lower carbon dioxide losses due to out gassing,
- Permit higher cell concentrations.
- Allow you to grow algae in any climate

However with the advantages come disadvantages as well. Namely,

- Cost
- Size and scope
- Technical expertise

The purpose of this book is to minimize the costs involved, expand the size and scope of home PBR's and provide you with the expertise to not only build a photo bioreactor, but then to scale up to any size necessary.

Design Notes

The purpose of an algae test incubator is three-fold:

- To have a ready supply of algae on hand so you aren't buying algae cultures continually.
- To have enough culture to be able to constantly "feed" your pond. This reduces the chances of contamination as well as maintains the integrity of the pond itself to the desired algae strain.
- Can also be used as a test bioreactor to test different strains and/or nutrients to maximize growth and production.

This is a "homemade" algae test bioreactor with harvesting base made from easily obtained parts. It's not pretty or sexy. It simply gets the job done.

Advantages:

- Inexpensive
- Easy to clean and maintain
- Can easily be built by amateurs.
- Customization easier:
  - Can install doors and insulation easily and cheaply to have an enclosed out of the way unit.
- Easy to fix if needed. Because it is "home built" from off-the-shelf parts, if something breaks or needs to be replaced, no costly replacement parts or specialists needed.

Disadvantages:

- It isn't "pretty" and won't impress any visiting dignitaries.
- Lacks professional quality parts.

One of the biggest complaints I get is how long and tedious the process of experimentation is with algae. There are hundreds of different variables and 1000's of different strains. Testing them all, one at a time is not only time consuming and pain-staking work, but truthfully, it is also out-and-out boring.

That's where this little baby comes in.

With it, you can…

- Test different strains.
- Test different nutrients.
- You can vary light
- You can vary air discharge
- Co2 can be added

What I like most about this design…well, there are A LOT of things I like about this design. But if I had to pick one it would be the ease of building, and how easy it is to take apart and put back together. It is a real pleasure working with this unit.

I didn't design this unit to be "pretty." It is designed to be functional, inexpensive to build, easy to work with, and do what it is supposed to do.

Other thoughts:

- The use of adhesives: Don't get married to the ones I choose. Silicones work well too. The nice thing about silicone is if you screw up, you just peel it off and start over. If you use PVC cement, be warned, it is forever.
- The parts list is as complete as I could make it. In some places you might find small things missing, (mostly things you would find in any shop) but everything major is accounted for.
- The variations of this design are endless. Feel free to modify and/or change as your situation warrants.
- Tubing is expensive. For this reason we chose an easily obtained and inexpensive material. This design could however be "beefed up" with better quality tubing.
- I also didn't go into detail here with automation. If you want to spend the time (or the dollars) you could easily make this whole system automatic.
- Maintenance is minimal. It usually consists of replacing the air stone. Simply disconnect the bottom cell assembly, pull off the old air stone and replace. Or, if you're cheap (Like me) then simply scrape the air stone with a razor knife and fit it back together again.

But for an inexpensive, build-it-yourself lab test unit, this design can't be beat.

This design is a variation on some other designs floating around. Acrylic tubes are a problem to find, and when you do, you pay through the nose. 5 gallon water bottles are everywhere and considered scrap by many people. Look around and you can get them for free.

Although the unit pictured here is a scale model, this PBR's can also be scaled to almost any size, using the same design.

There are a number of advantages using this design.

- It's easy to calculate volume.
- Extremely easy to build
- Very inexpensive to build.
- These units hold the most volume, and a small space.

- Easy to harvest.
- Easy to clean and maintain.

Notes regarding procuring the 5 gallon jugs:

At supermarkets they want you of course, to buy the water to get the jug. Go to the store manager and tell them you wish to buy the jugs, but only wish to pay the deposit as you won't be buying any water. This will easily halve the cost of the jugs. Most will do it. If they don't go to another supermarket.

Another method is asking existing businesses if they will part with their for the price of the deposit. Many businesses have 10-15 empty containers at any one time.

Still another method is to go directly to where they bottle the water. Many times you can get them free.

TRY TO GET THE WATER BOTTLES WITH THE SCREW ON TOPS. The slip on tops don't work as well.

To scale up simply make your base 6 foot instead of the 24" pictured here. Use a 2"x6" as the bottom support brace and/or add more support for the bottom brace.

Harvesting: Simply disconnect the air hoses and lift the unit out by the handle. It can be easily poured from the top into your harvest chamber.

Cleaning: Simply use a hose and cloth and clean the inside normally.

You can also use this design indoors or outdoors.

When to Use a Bottle PBR

Bottle PBRs are a good intermediate PBR between testing and scaling up to full size. They are very inexpensive to build, and hold a lot of algae culture.

Bottle PBR's get around the high cost of acrylic tubing, yet you still maintain high volume and high density you get with tubes.

Bottle PBR's are also excellent in your in-home algal lab. You can set them up in a spare room. They can also be used to maintain your algal cultures in cold weather when having an outdoor PBR is not practicable.

PBR Advantages and Disadvantages

Advantages:

- **Prevent contamination:** One of the biggest problems with opens ponds (in my view anyway) is they are susceptible to contamination from invading and/or native species. In a PBR all inputs are completely controlled by you, not chance or nature. This is a HUGE advantage.
- **Allow you to grow algae in any climate:** This is one of the main reasons for a PBR. It allows you to grow algae easily and cheaply in almost any climate. Open ponds are an unacceptable alternative in many colder climates.

- **PBR's offer better control over existing conditions:** Since you're controlling all the inputs, you can also (better) control the existing conditions of your algal experiments. Meaning climate, light, temperature, Ph balance, nutrients, etc. Many times this isn't possible in an open pond situation. For example it is hard to control the amount of sunlight in a given location. However with a PBR it is as simple as resetting a timer.

- **Prevent water evaporation:** Water evaporation in an open pond can be difficult situation to control. Where water is scarce this makes open ponds an unacceptable choice.

- **Lower carbon dioxide losses:** If you have a unlimited source of waste carbon dioxide this isn't a problem, however most home users aren't in a situation of living next to a power plant…they have to buy it in canisters. In order to minimize costs, this becomes a consideration.

- **Permit higher cell concentrations:** Because you're controlling the parameters of the PBR, you can also control the density of your cell colonies. While possible in an open pond, it is much easier in a PBR.

Disadvantages:

- **Cost:** Until now, PBR's were considered the realm of corporations due to the high cost of fabrication. Indeed the high cost of acrylic tubes, especially as the price of oil increases, is enough to give one pause. The key to controlling the cost of PBR's is in "Yankee ingenuity" Sure, it's always possible to complicate things and charge extra. No problem there. However to use existing inexpensive, local resources to create a PBR the knowledge has been non-existent. Until now. That is one of the main reasons for producing this book.

- **Size and scope:** For the most part, PBR's have been confined to laboratories with relatively few being fabricated for large scale production. That is now changing. The size and scope of your PBR is also dependent on your application. Many (most) uses don't require a large scale PBR…health food supplements, for example. You can easily make all the Spirulina and/or chlorella your family would need with a small PBR. Algae bio fuels for example, go to the opposite end of the spectrum. Here you need to produce a large amount of algae to be successful.

Technical Expertise: Here is what one forum board "expert" had to say …

> "What you will need to read before starting with a design of a bioreactor is:
> 1. Physics of fluids (viscosity, velocity, laminar and turbulent flow), light (wavelength, brightness), pressure.
> 2. Fluid flow mechanics for Newtonian and non-Newtonian fluids.
> 3. Thermodynamics (basics).
> 4. Heat transfer through different materials.
> 5. Mass transfer in different media (gas transfer from sparger to fluid, and from fluid to cell).
> 6. Light transfer (when interested in PBR).
> 7. Basic biology of the cell (plant cell, when interested in PBR for algae production).
> 8. Chemistry (basics).

9. Mathematics (differential equations).
10. Be extremely careful with experimental design, when decided to proof that some PBR works.

Summary: PBR design is extremely complex task, and I will advise anyone who is not an expert in the field not to take any chances by designing it by themselves. It simply will not work."

The only thing he left out was quantum physics and brain surgery.

Nothing could be further from the truth.

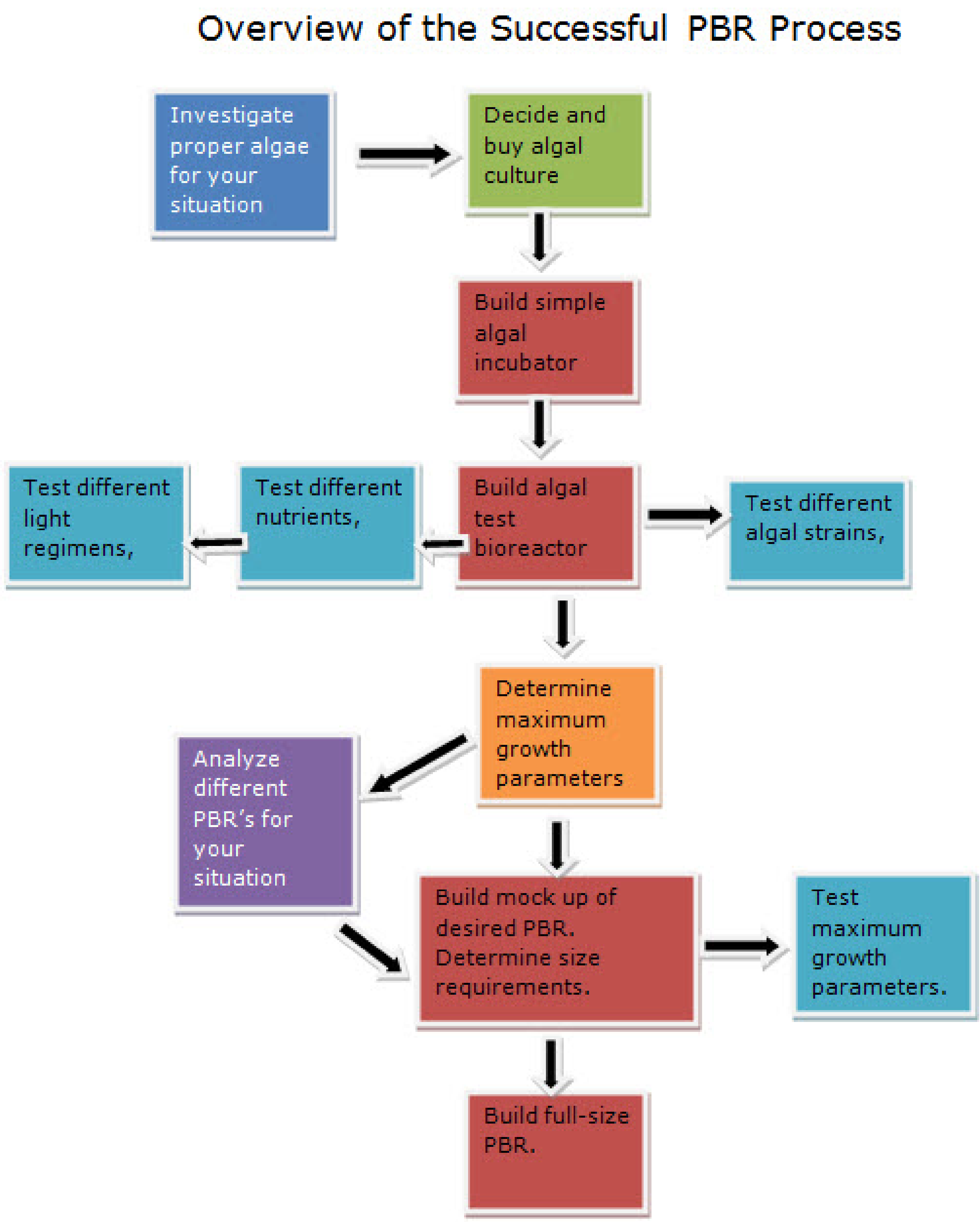
Here is the knowledge you REALLY need…

- The ability to use basic power tools without injuring yourself or others.
- This eBook
- A brain
- About $200 bucks.

And that's about it. Since you bought this Ebook, it's obvious you have a brain. You're 50% of the way there already. :+) With those 4 things you'll be able to build, operate, and grow algae in a PBR.

My point here is you DON'T HAVE TO OVER-COMPLICATE THINGS.

Sure, more knowledge is better than less. (After all, that's why you bought this book, right?) But the above is like saying you need to be a NASA shuttle commander to fly a paper airplane.


Overview of the Successful PBR Process
Investigate proper algae for your situation
Decide and buy algal culture
Build simple algal incubator
Build algal test bioreactor
Test different nutrients,
Test different light regimens,
Test different algal strains,
Determine maximum growth parameters
Analyze different PBR's for your situation
Build mock up of desired PBR. Determine size requirements.
Test maximum growth parameters.
Build full-size PBR.

Detailed Parts List

Materials needed:

(1) T-5 "Sunblaster"

(5) l 1" x 2" x 8' foot pine strips

(1) 1/2" PVC 90 degree elbow slip/thread

(1) 1/8 x 1/4 brass MIP barb

(1) 1/2" PVC Slip and threaded Male adaptor

(1) 1/2" Brass reducer

(4) 1/2" Brass Bushing

(1) XP60 air pumps

(4) Bulk air stones

20' vinyl air hose

(1) 4-way air valves

(1) filtered check valves

(2) drawer slides

(2) Door handles

(2) 5 Gallon water bottles

(1) Eco 100 submersible pump

12 gallon tote

(1) power strip

1 temp. controller

(1) lamp timer

1- 1.25 inch pipe clamps

½" x 5' black hose

(1) 2” inch to 1.5” inch rubber reducer

1.25” ball PVC valves

(1) 1.25” PVC “repair” Coupler

(1) 1.25” PVC Cap

Test Bioreactor Fabrication

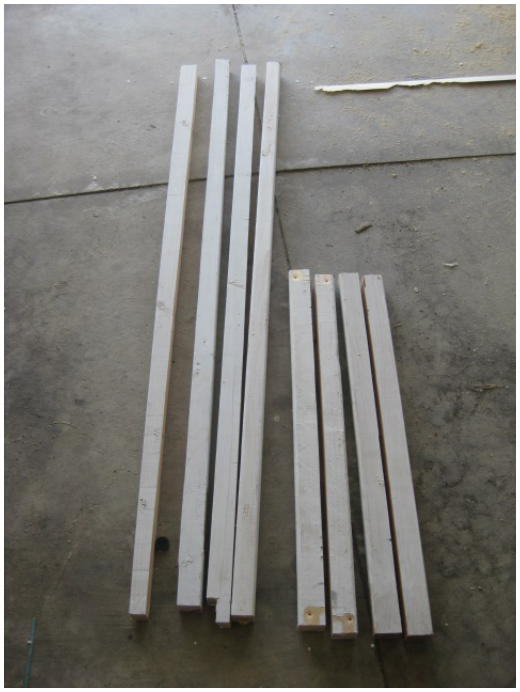
Building the Frame

Parts Needed:

- (5) 1” x 2” pine strapping
- (1) 2’ x 4’ plywood
- (2) drawer slides
- (2) pull handles

Tools Needed:

- Table saw
- Drill
- Screwdriver
- Screws



Fabrication:

“Rip” on a table saw (or buy) 3- 2”x 4” x 8’ pine boards at 5’ foot to make the desired number of uprights.

Cut 12 more at 14” inches

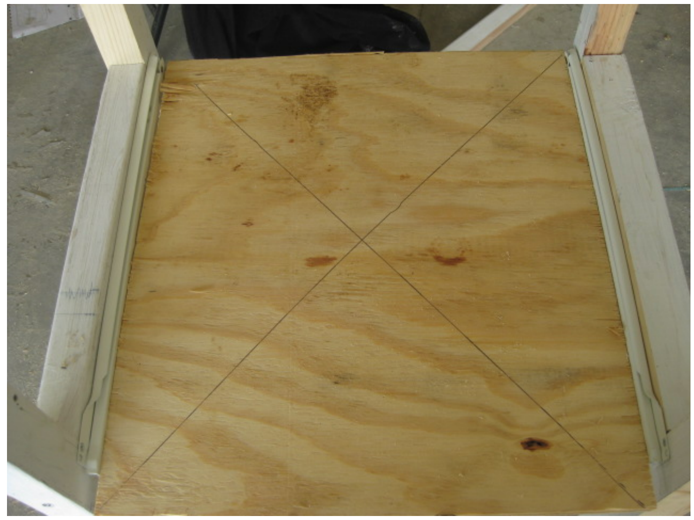
Build a basic rectangular frame 5’ foot high and 16” (on center) wide.

(optional, but handy) Add one set of drawer slides on the bottom

Add a handle

Add another shelf and drawer slides at 28” inches from the bottom.

The frame should be looking like this now.



Draw an “X” from each corner of the top shelf. Make a dot about 1” in front of the center point of the “X”.

Cut a 6” inch to 8” inch hole using the dot as a center guide.

Building the Bio-Cells

Materials needed:

- **(35) 5 gallon water jugs**
- **(2) tube silicone**
- **(3) 5” hose clamps**

Tools Needed:

- **Power drill**
- **1/2” inch drill bit**
- **Jig Saw**

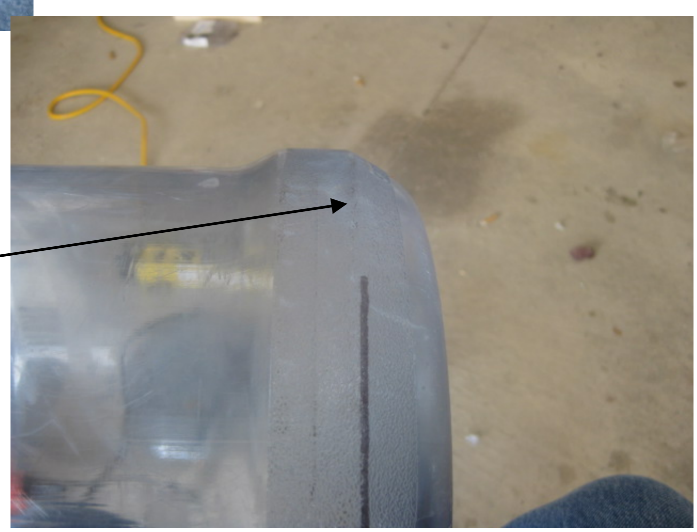
Fabrication:

OK, listen up. This isn't difficult but you'll need to pay attention here. It can get confusing. I'll make this as painless as possible. But you have to get this step right, or the entire unit is going to fail for (soon to be) obvious reasons.

1.) With a permanent marker, draw a ring around the part of the opening just as it narrows.

2.) With your jig saw, carefully cut the end of the opening off.

3.) On the BOTTOM of the bottle, with your marker make a line JUST AS THE BOTTLE STARTS TO CURVE.



4.) With your ½" inch drill bit, drill a small hole towards the bottom and top of the bottle as close to the line as you can.

5.) CAREFULLY, with a jig saw, saw around your line. Try to make this cut as smooth and even as you can.

6.) Fit your water bottle upside down into the frame. It should fit straight up and down, with about ½" inch of clearance in the back.

7.) Take your next bottle and make your mark where the top portion meets the bottle. Drill a ½" hole as before TOWARDS the top of the bottle.

8.) Make another mark on the bottom like you did before JUST AS THE BOTTLE STARTS TO CURVE INWARD. Drill a ½" hole on the bottom side of the line.

9.) At this point it may be a good idea to fit the TOP of the bottle into the BOTTOM on the one below so you can see how they are going to fit together.

10.) Once you have your line drawn, and your holes drilled, cut the top AND BOTTOM off as evenly as you can.

11.) Apply a ring of silicone around the curved edge of the water bottle.

12.) Now apply another ring of silicone where the 2 pieces meet on the outside. Do this carefully, and fill any gaps you may have in the joint.

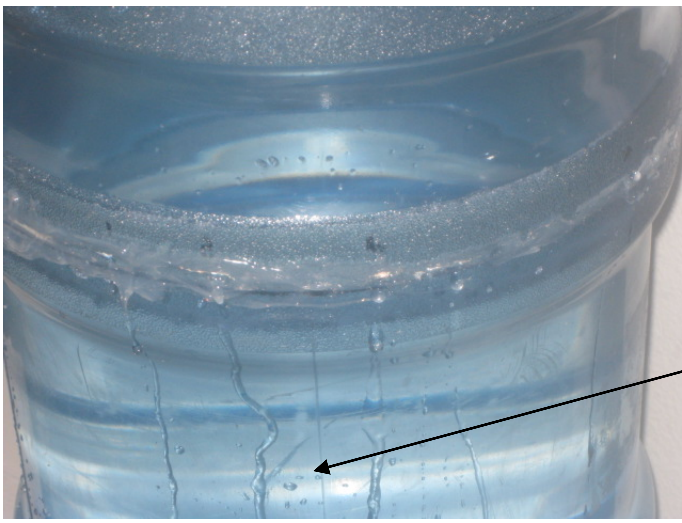
13.) At this point I would also try to level and get the base as straight as possible.

It should be looking like this now.

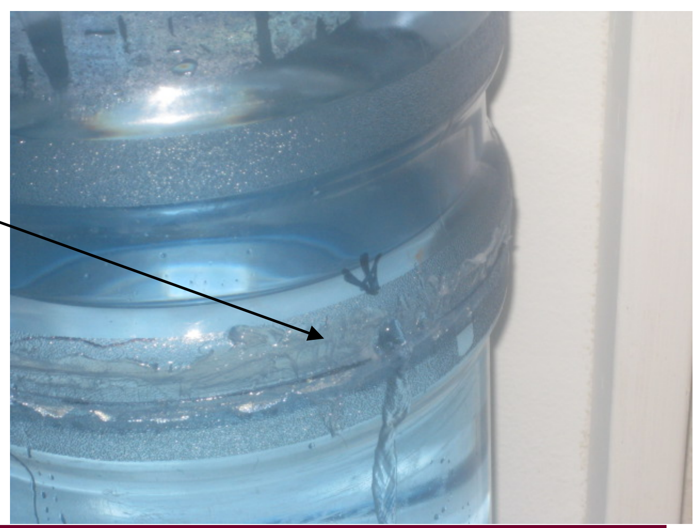
Once these are built, it is time for the …Water test.

1.) For this you'll need 1.25"inch ball valve, a 3" nipple, and you 2" inch to 1.5" inch reducer. Put them together as you see here. Don't glue them…just put them together.

2.) Attach the 2"inch end to the bottom of the 5 gallon water bottle. Make sure the ball valve is in the closed position.



3.) Fill the bottle with water 3" inches or more past the joint. You'll almost always find some leakage…don't worry.



4.) Make a mark where you see the leak.

Drain the water from the bottle, allow to dry, and re-caulk the leak. Doing this after every joint, will ensure the bottle as water tight.

Now add the 3 hose clamps around the seam. You'll need to unthread them completely, then thread one into the other until you get one large clamp with 3 screws to tighten.

You don't want this too tight to misshape the seam, just to add support. This part may be a little over kill, so use your best judgment.

Once it is in place, fill the bio cell again and check for leaks. Re caulk as necessary. Then let the whole unit dry as necessary.

Air stone/Ball Valve Fabrication

Materials needed:

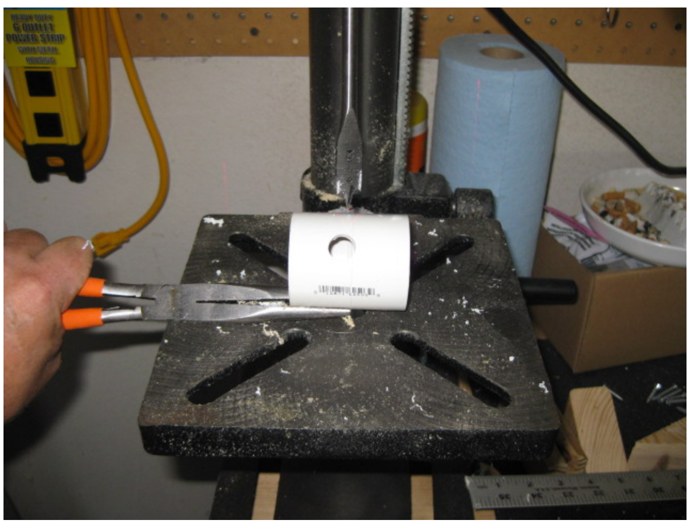
- (1) 1.5” inch PVC “repair” couplings
- (1) 1/8” x ¼” MIP Hose Barb Adapter
- (1) ¼” FIP Elbow Adaptors
- (1) 1.5”inch 1.5” PVC nipples. (cut from 1.25 inch PVC pipe)
- (1) Air stones
- (1) 2” inch to 1.5” inch rubber reducer
- (1) 1.25”inch ball valves
- ¼” inch air hose
- 3M Marine silicone

Tools Needed:

- Vice or clamps to hold coupler
- Drill press and ½” drill bit

Fabrication:

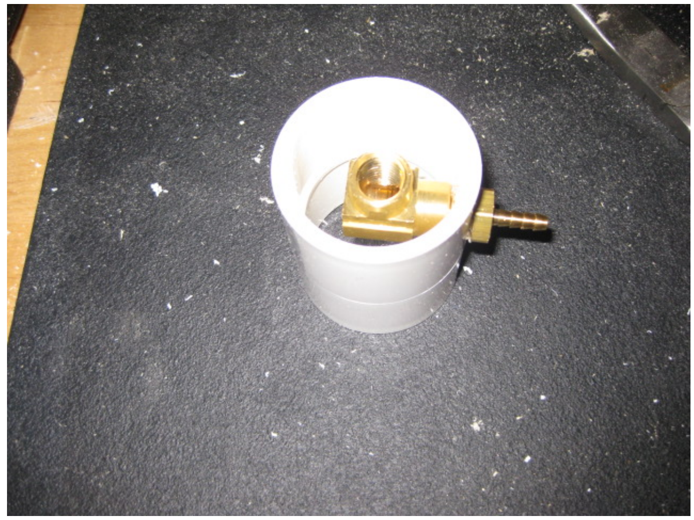
1.) Make a dot on the center line of repair coupling.



2.) Using a ½" drill bit, drill a hole so that the TOP of the (drilled) hole is just over the centerline.

3.) Put a ring of silicone around the top of the thread and screw the hose barb into the coupler so that the barb is facing outward.

4.) Screw the ¼" FIP Elbow Adaptors on the INSIDE of the coupler.



5.) Attach second hose barb to inside of elbow, then cut a piece of air hose about 1.5"inches and attach to air stone.

6.) Attach air stone to inside hose barb.

7.) Cut 2" inch nipples from length of PVC pipe.

8.) The completed air stone assembly should look like picture on left.

9.) Lay out the coupler/air stone, 2" inch reducer, nipple, and ball valve.

10.) Attach the 1.5" inch end of the reducer to the air stone/coupler assembly.

11.) Using the PVC cleaner and cement glue the nipple to the other end.

12.) Cement the ball valve to the nipple.

Add the ball valve to the assembly.

Fabricating the Bio  Light

Material Needed

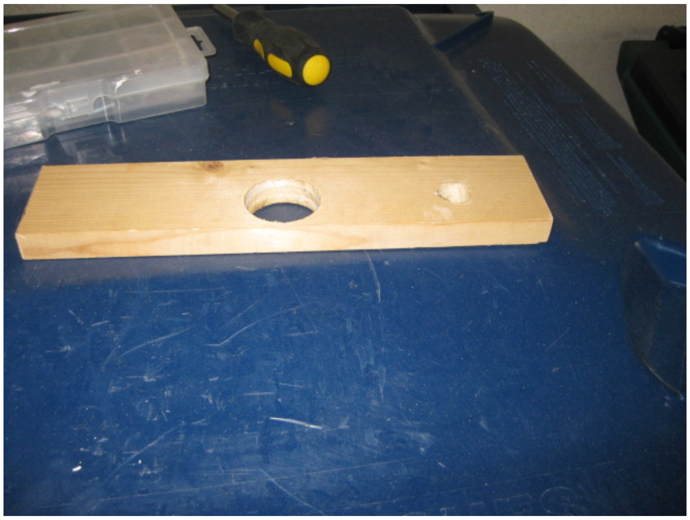
- (1) 5’ foot T-12 tube protector
- (1) 1.25” inch PVC 90 degree elbow
- (1) T-5 “Sunblaster” light
- (1) 1.25” inch PVC cap.
- (1) 1.25” pipe strap
- Bolts, rubber gaskets, washers, nuts to fit

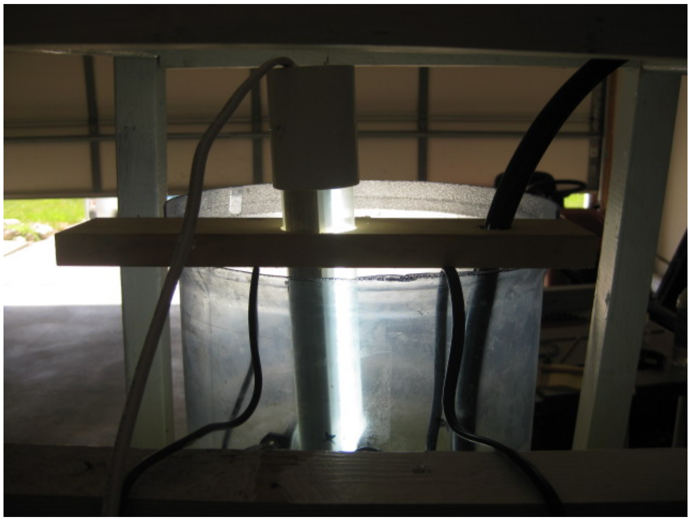
Tools needed

- Saw
- Silicone and/or PVC cement
- .Adjustable wrench

Cut a 1" x 6" inch pine board to fit across the top of the bio cell.

Then cut a 1.50" inch hole in the approx.. center as well as a ¾" home towards one end. Save the 1.5" inch round "donut" cut from the board.





Cut a notch in the back of the bio cell to fit the pine board.

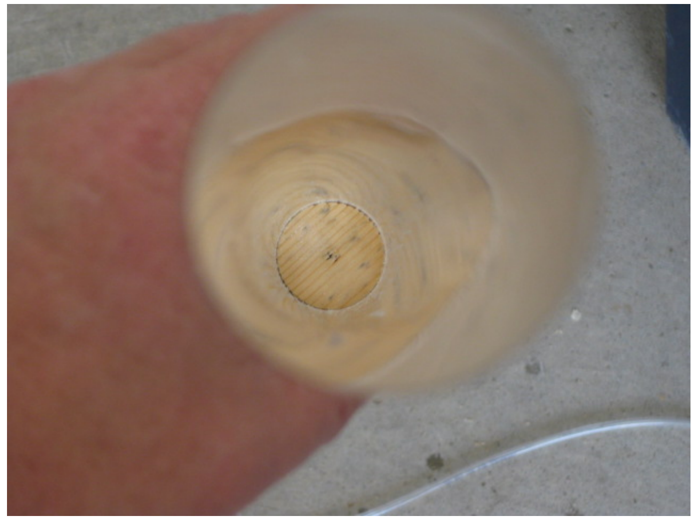
Measure and cut the T-12 tube protector from the bottom of the biocell to the top over the pine board

Add the 1.25" cap to the bottom and silicone.

Once dried, test for water leakage. (MAKE SURE this is absolutely watertight) When

watertight fill the bottom of the cap with sand.

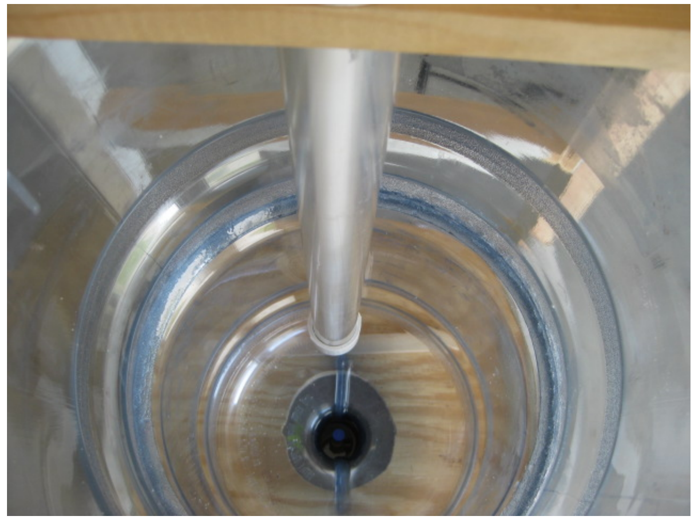
Level the sand, and use the “donut” cut from the pine board and push it all the way to the bottom. Tamp gently to level and seat the wood plug.



Insert the T-5 Sunblaster into the 1.25” T-12 protector. Don’t push it all the way down the tube.

Add the 1.25” slip fitting to the top

Disconnect fitting and slip through hole in pine board, then add slip coupler again. It should be able to easily move up and down through the hole cut in the pine board.

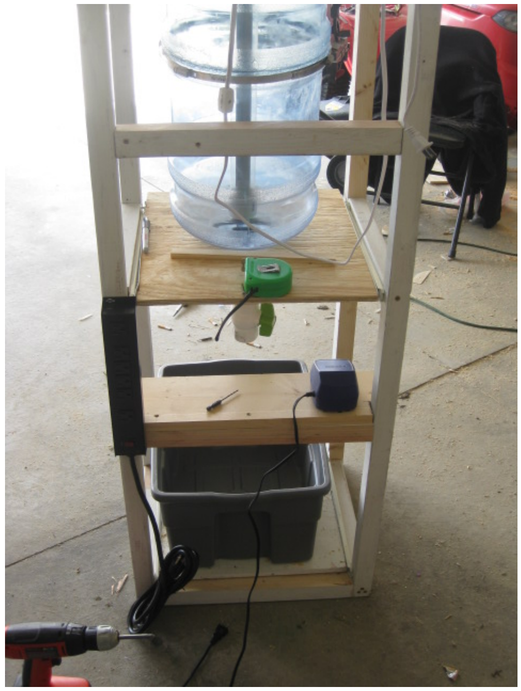


Add the T-5 light connector for power.

Add the 1.25” pipe straps above the waterline.

Test the light. It should sit in the cradle easily.

Adding Power, Temperature Control, Pump, and Air Systems



Material Needed:

- Power Strip
- Air Pimp
- Air Line Tubing
- Submersible pump
- ½" inch tubing
- Small screws

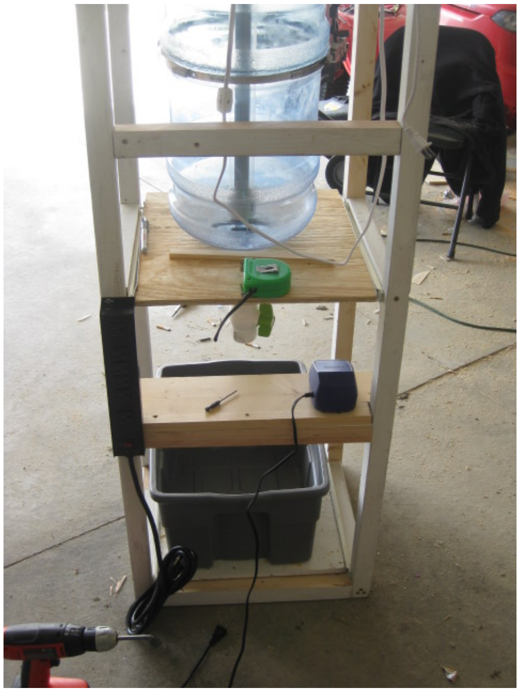
Tools Needed

- Razor knife
- Screwdriver

Cut another piece of pine board and notch the ends to fit

Add a cross piece for support and screw pine board to back of frame.

Add the power strip to upright on frame.



Set up air pump and run air line to fitting on the ball valve.

Add the ½" hose barb fitting that came with the pump into the top of the pump. Set the pump into the harvest tank on bottom shelf.

Connect the ½” black hose to the hose barb and run from pump to the top of the bio cell.

The hose goes through the ¾” hole in the top plate.

Add lamp timer to light and set.

At the point you can fill the test bioreactor with water and test all the systems

The Test Bioreactor in Action

The fabrication of the “seed” incubator and the test bioreactor is very straight forward. There is nothing fancy, or complicated about either one. If you buy all the parts you might spend $250 total for them both. Since I had most of the parts laying around my garage, I might have spent $15.

Now the question is, does it work?

For this test I’m using Chlorella Vulgaris. I seeded it in my incubator and added it to tap water.

- I added 2 teaspoons of sugar each day (for 5 days)
- I added 2 teaspoons of 13-13-13 all purpose (garden) fertilizer. (for 5 days)
- The light regimen is 12 hours on, 12 hours off.
- pH is 7.5 (maybe too low)
- Air flow is set a full bore. (also could be too high)

Day one:

Day Two

Day Three

Day Four.

Notice the growth starting on the seams.

Day Five:

Day Six.

Day Seven: Note: the change in color.

Harvesting

Harvesting can be accomplished easily and inexpensively using a 10 micron "bags" you can find at http://www.cfsco.net/ or a number of other places on the internet. These bags cost in the neighborhood of $5 USD and can be used repeatedly.

Simply attach the bag to the ball valve with a twist tie and open the valve. As long as the bag stays above the resevoir it will drain.

After 7 days the yield of the bioreactor is disappointing, a few grams, at most. This experiment with the nutrients I used, in the amounts I used them in, is not a good combination.

Notice the color; some sort of contamination also took place. I was hoping to show you a nice little yield of algae, but this is real life folks.

At this point you start over with a new batch. (You did leave some in the seeding incubator, right?)

Like I said, trial and error.

Test PBR Parts List

	Part name	Num. of Units	cost per unit	Total	buy offline	Part number
☐	1/2" PVC Slip and threaded Male adaptor	1	0.32	$0.32	Home Depot	26012
☐	1/8 x 1/4 brass MIP barb	1	2.88	$2.88	Lowes	25673
☐	1/2" Brass reducer	1	1.97	$1.97	Home Depot	72501
☐	1/2" Brass Bushing	1	$3	$3.00	Home Depot	72602
☐	3M Marine adhesive	1 tube	3.98	$3.98	Lowes	70512
☐	1"x6"x8' pine board	1	$5.76	$5.76	Home Depot	4410425
☐	2" x 4" x 8' pine stud	5	1.84	$9.20	Home Depot	161640
☐	2.50" wood screws	1 (pkg)	4.97	$4.97	Home Depot	23465
☐	XP60 air pumps	1	17.99	$17.99	Petsmart	73725702295
☐	Bulk air stones	1	0.49	$0.49	Petsmart	73725702185
☐	20' vinyl air hose	1	2.98	$2.98	Home Depot	25493
☐	filtered check valves	1	2.29	$2.29	Petsmart	73725702175
☐	4-way air valves	1	9.99	$9.99	Petco	532673
☐	5 gallon water bottles	2	$6.99	$13.98		
☐	Door handles	2	$2.79	$5.58	Home Depot	51844
☐	T-12 Tube Protectors	1	$3.78	$3.78	Lowes	163817
☐	Eco100 Submesible Pump	1	$10.99	$10.99	hydroponic	online
☐	1/2" black hose	6 foot	$5.99	$5.99	Lowes	
☐	1.25" ball valve	1	$3.99	$3.99	Lowes	21487
☐	Temp controller	1	$37.49	$37.49	hydroponic	online
☐	1.25" PVC cap	1	$0.72	$0.72	Lowes	23989
☐	1.25" PVC coupler	1	$0.72	$0.72	Lowes	23658
☐	T-5 Sunblaster Light	1	$29.63	$29.63	hydroponic	online
☐	1.25" pipe clamps	1	$1.98	$1.98	Lowes	115982
☐	5" hose clamps	3	$1.99	$5.97	Lowes	
☐	66 quart storage bin	1	$10.27	$10.27	Lowes	336492
☐	Drawer Slides	2	$11.96	$22.92	Home Depot	95916
	TOTAL			$220.03		

Notes: : 5 gallon water bottles can be bought at most supermarkets. Don't buy the water, ask to pay for the "Deposit."