Design for Manufacturing, Reliability, and Economics

Design and Development of an Automated Continuous Harvesting System for Microalgae Photobioreactors

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I. Introduction

Designing for manufacturing is important in order to prepare for production of a product or system. In the design of our system, we used this concept and planned for our system to use parts that were already available either by a supplier, with only critical parts being designed and manufactured by us. In order to account for reliability, we kept the amount of parts being used to a minimum, and only included moving parts and electronics where absolutely necessary. Finally, because of our budget constraint and project goals, we focused on keeping our budget to a minimum. This way, the customer is only expected to make an initial investment in order to begin growing algae and producing oil.

II. Design for Manufacturing

1. Overview

When developing the prototype for the microalgae airlift, we relied heavily on the reusability of parts available to us that matched our design objectives. We wanted a mobile lab scale system that would house all of the components necessary for cultivation, PEF lysing, and extraction. In order to do this we planned a vertical system which would maximize the efficiency of space so that it can comfortably fit in a small lab.

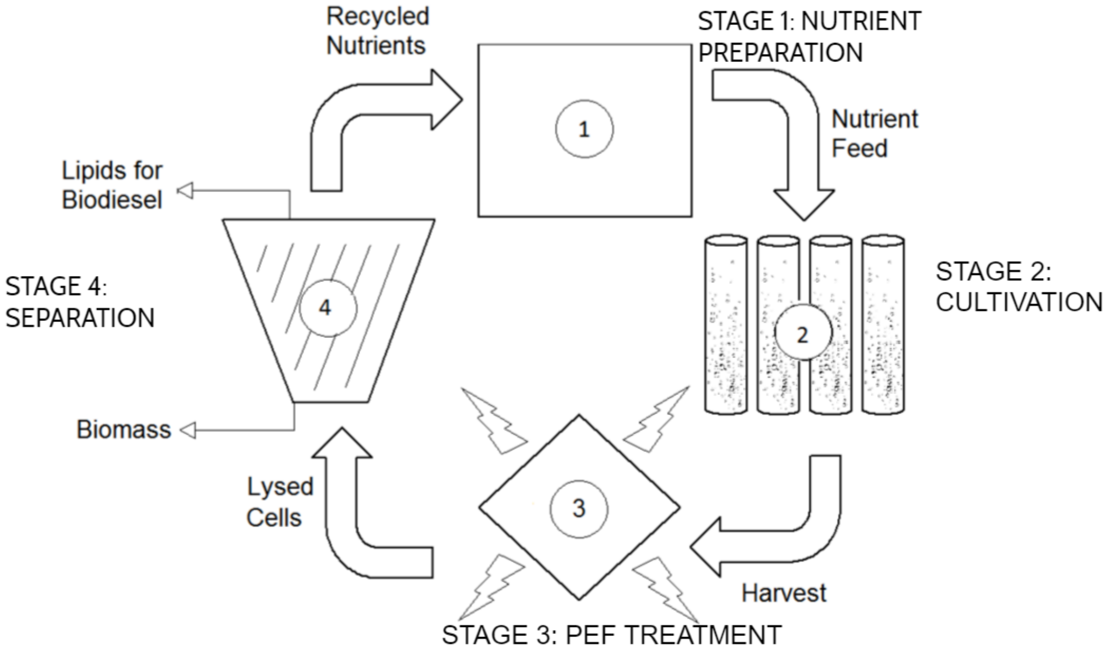

Figure 1. Flowchart displaying operation of the microalgae cultivation and harvesting

2. Prototype Assembly

Although most parts of the project were designed at one time, the prototype was assembled in the same order as the flowchart shown by Figure 1. Beginning with the Nutrient preparation stage, and then continuing with the cultivation stage, PEF lysing treatment, and finally the separation stage.

A cart that was located in our lab was selected to be the main structural component of our system. A diagram of what our system looks like is shown in Figure 2. Once the cart had been selected, we began attaching the airlift tubes to the back of it and adding the light fixtures. The tubing and holes used for the cultivation were added in order to allow for the nutrient preparation and the transfer of algae. Additionally, control boxes were designed, laser cut, and pieced together with the IR/LED Transistor pair that detects if the algae has grown to its desired density. These control boxes are attached to peristaltic pumps and solenoid valves to control the flow of algae from one airlift tube to the other. The electrodes for the PEF Lysing system were designed using CAD, and machined from aluminum by the FAMU-FSU College of Engineering machine shop. The chambers were also designed in CAD and are being fabricated out of Delrin plastic. Finally, the lamella clarifier is being built at UFPR and will be added to the system.

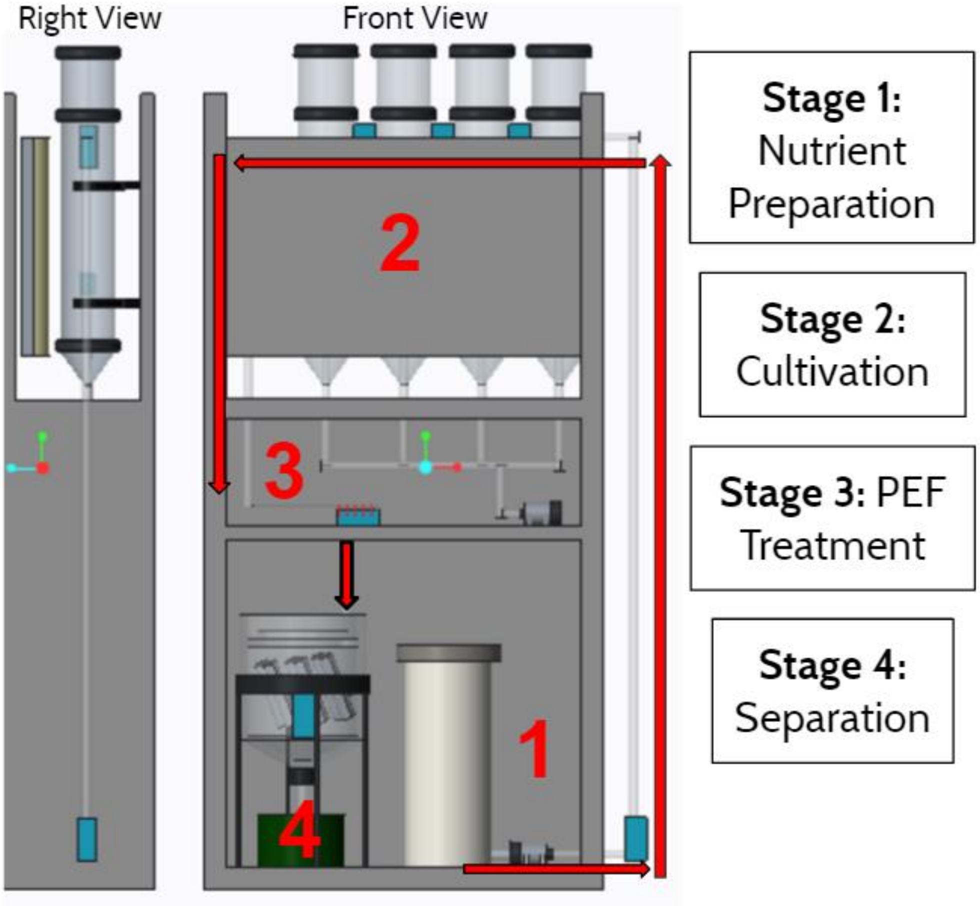

Figure 2. Diagram of the airlift build

The time taken to assemble the project, when taken continuously, is relatively short. Most of the loss of time was due to waiting for supplies to arrive, or for our order to go through the machine shop queue. The assembly took slightly longer than anticipated due to some delays caused by machine shop errors as well waiting for parts to be shipped or made. In order to improve on these delays in the future, an estimate of how long it will take to make or ship each part should be made, and that estimate should be taken into account when planning the build order.

The amount of time taken to build the prototype could have also been reduced by creating less components. For example, using less airlifts and keeping the algae in one larger container may have simplified the process. The downside to this is that we have less control over batches of algae and how much is growing at each time. Figures 4 and 5 both show exploded views of all the project components.

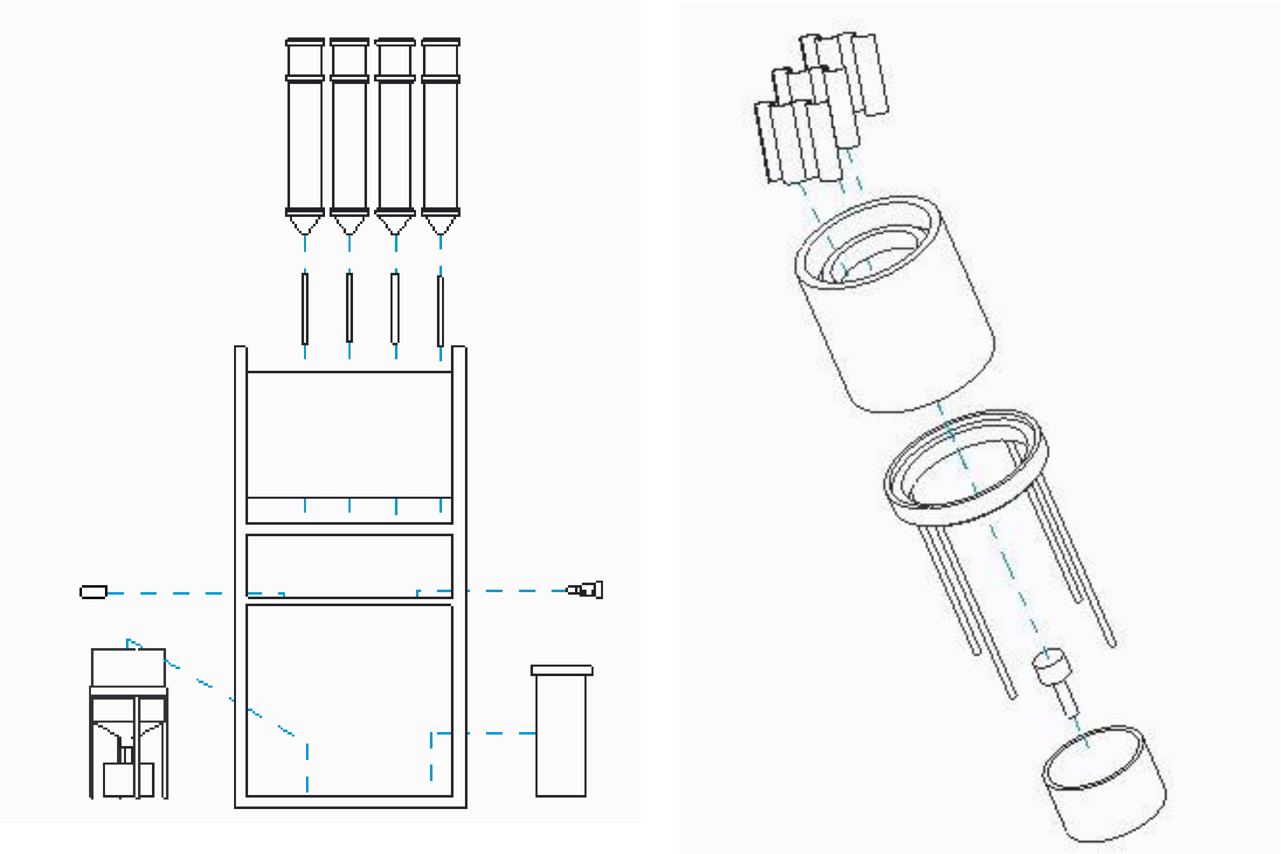

Figure 3 a,b: (a) Exploded view of entire prototype. (b) Exploded view of lamella clarifier.

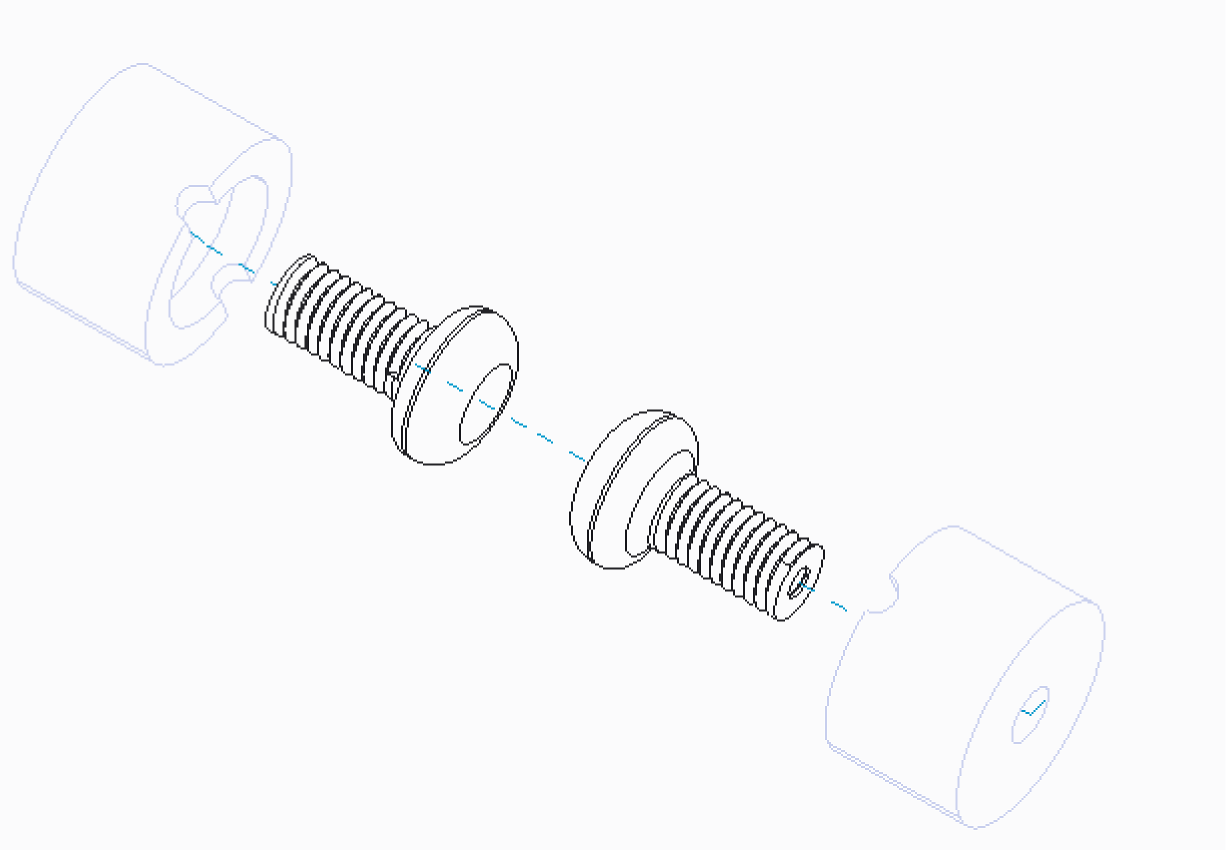

Figure 4. Exploded view of the Lysing chamber and electrodes

III. Design for Reliability

The prototype performs very well under our testing, and over type it should continue to do so as long as basic maintenance is performed and the pumps and pipes don't get clogged. These problems should already be prevented by our design however, since the system is continuously flowing. This should help prevent the clogging of parts. The main reliability concerns for our project are leaks, which can develop over time due to the water eating escaping through tube connections. We have addressed these by sealing the locations of concern with epoxy glue and making sure that the connections are reliable. If issues arise in the future, we are willing to fix these issues for our customers. A Failure Mode Effect Analysis of the potential problems is shown by Table 1.

Table 1. Failure Mode Effect Analysis

Step	Failure Mode	Failure Effect	S	Causes	O	Controls	D	RPN	Action
Algae Transfer	Leak	Unhappy customer	7	Bad connection	4	Epoxy sealing	9	252	Regularly lookout for leaks
Algae Transfer	Clog	Ineffective lysing	5	Improper maintenance	2	Continuous running	6	60	
Lysing	Ineffective lysing	Failed extraction	7	Piping clog	1	Preventing a clog	5	35	
Extraction	Oil doesn’t separate	Unhappy customer	7	Ineffective lysing	1	Preventing a clog	6	42	

IV. Design for Economics

The cost for the system can be separated into two main components, cultivation, and harvesting. The cultivation portion is the more costly of the two. Depending on size and materials it varies greatly, as a photobioreactor can be as small as a 5 liter airlift tube or as big as a 15,000 liter photobioreactor. Of the two cultivation systems mentioned, airlift systems seem to have larger yields per volume but are usually smaller in scale compared to photobioreactors which, in industry are typically larger in volume. The cost for the cultivation component of the system is usually a one time, up front capital investment, apart from the nutrients if using synthetic nutrients, while that of the harvesting can amount to a recurring expense, albeit a small one. The capital cost is very small as compared to that of the cultivation and the recurring expense refers to the energy cost of running the pulsed-electric-field lysing.

The built prototype cost less than $720. With the more expensive items being associated with the cultivation infrastructure and automation components such as pumps, valves and sensors. The support rig for the entire system is estimated to cost a total of $200.00 .The automation of the entire system, cultivation and harvesting, cost approximately $300.00 The harvesting components were relatively inexpensive. The component list and prices is as follows: Electrodes, $21.00; High voltage pulse generator, less than $10.00. Electrode chambers and mount, less than $10.00; and separation tank, approximately $50.00. A breakdown of the expenses for this project is shown by Figure 5, including the cost of the algae used for production and testing.

Based on the large photobioreactors at UFPR, Brazil, 12,000 liters, the cost of construction is approximately $41,000. This of course can differ depending on whether glass or pvc tubes are used, or what grade of pvc is used. The cost also varies by region and building a large photobioreactor will usually have a lower cost per volumetric liter. Airlifts are easier to construct and require less labor therefore are cheaper. The drawback being, airlift configurations aren't as compact as photobioreactors.

The harvesting component cost mainly refers to the Pulsed-Electric-Field (PEF) lysing and the separation tank. The pef lysing doesn't have to be scaled up for larger systems, when speaking of component size. A larger, volumetric, system will just harvest larger mass flows, therefore the pump must be scaled up respectively. The pef system will just have to be programmed to a higher frequency to maintain lysing effectiveness. A scale up in pump is relatively cheap comparably as shown in the table below. The greatest cost in harvesting comes in the scale up of the separation tank; as large volumes of cultivation yields large harvests and settling and separation rate is slower than harvesting rate therefore large tanks are needed to account for this. Typical cost of a separation tank for is approximately $1.00/gal.

Since lowering the cost cultivation wasn't within the scope of this project, the price for the cultivation system remains the same as commercially available at the moment, amounting to the highest expense. The true value in the system comes from the harvesting, and the increased production for the same volume of cultivation. The harvesting component eliminates the added cost of chemicals for flocculation, and energy cost of centrifugation and drying. These post-processes have a very large energy demand and therefore high operating cost and labor cost. This system eliminates these issues, increasing profit.

Only one other similar product was found, in development by OriginOil, the Single Step oil extraction aims to achieve the same as our harvesting component. The OriginOil system uses electromagnetic pulses to lyse the algae cells to extract the oil. Although the system is very similar to out harvesting component, there was no company which incorporated both phases, cultivation, and harvesting, in one system like ours. OriginOil's Single Step system is not available on the market yet and therefore has no price tag. Many similar cultivation systems exist today and vary widely in price. Table 2 shows a comparative of material cost. Although PVC is the most expensive, it is also the preferred material for its durability. The amount of fittings depends greatly on photobioreactor geometry, configuration, and size.

Table 2. Material Cost

Material	**$/ft**	**$/fittings**
Glass	5.3	19
PVC	10.75	10
PET	0.9	5

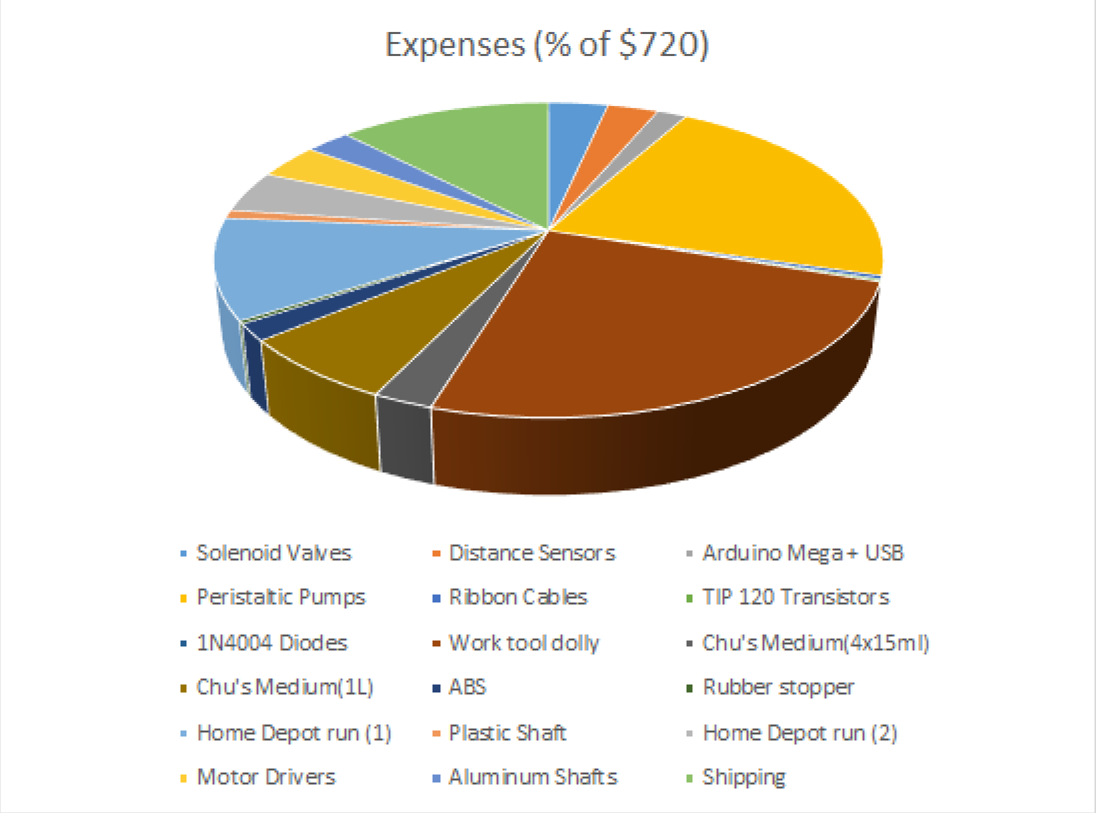

Figure 5. Pie chart of expense breakdown

V. Conclusion

The importance of planning a design for manufacturing, reliability, and economics cannot be understated. Each of these factors was taken heavily into account when considering the design of the system's components. In order to keep manufacturing complexity and time down, parts were reused and minimized. The reliability of parts was taken heavily into consideration with the main concern being leaks in the piping systems. These were reinforced with epoxy in order to prevent failures. The prototype created for this system cost less than 1,000 USD which achieves the goal of a maximum 1,500 USD budget. The rest of the budget was spent on algae used for growing and testing of the system,

References

[1] "A SUMMARY OF SOME COST INFORMATION..." A SUMMARY OF SOME COST INFORMATION... Web. 01 Apr. 2016.

[2] Crocker, Mark, Dr. "Low Cost Photobioreactor For Algae Cultivation." Tech Facts. University of Kentuck'y Center for Applied Energy Research. Web. <http://www.caer.uky.edu/techfacts/TechFacts-BEC-Algae.pdf>.

[3] "OriginOil." OriginClear RSS. Web. 01 Apr. 2016.