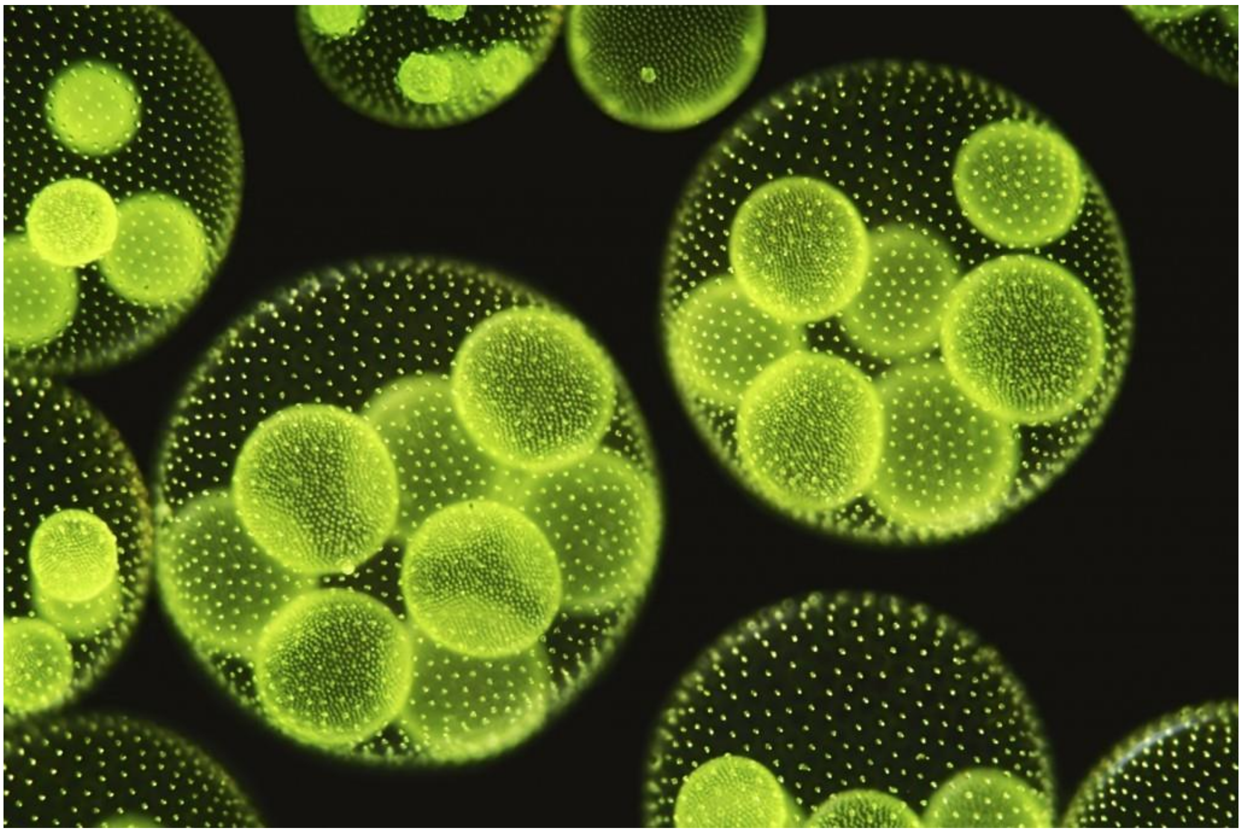
Photobioreactor For Microalgae Cultivation



Team: UIdaho PBR

Members: Samuel Funk, Matthew Jungert, Sage Pratt, Luke Becia, Nate Wiedenmeyer

Advisor: Dr. Dev Shrestha

Staff Mentor: Chad Dunkel

Client: Dr. Brian He

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EXECUTIVE SUMMARY

The goal of this capstone project was to design and manufacture an airlift photobioreactor for the cultivation of micro algae. This report provides an analysis and evaluation of the current and prospective project specifications, planning, deliverables and design evaluations for the airlift photobioreactor. The methods for analysis include FEA analysis, fluid flow calculations, resonance time and stability of finished product. Other calculations were done in TK solver to solve for bubble diameter and things to ensure the sparger would create enough lift to cycle the system.

BACKGROUND

Photobioreactors are devices often used to produce micro algae commercially. Some of the challenges of photo bioreactor design are supplying sufficient light to the micro algae and preventing the micro algae from sticking to the sides of the bioreactor. There are a range of designs currently in use, including open ponds, water filled flexible plastic bags, and long glass tubes. Each of these have issues, either with light penetration, cost, or reliability. An airlift design that solves each of these issues effectively is the goal of this group, since they are inherently low power, low maintenance devices. The completion of this project will enable the fast culture of most microalgae to be used for research purposes in the fields of biofuel generation and environmental impacts.

PROBLEM DEFINITION

The goal of this project is to build a bench scale photo bioreactor for micro algae cultivation. Micro algae are an excellent resource with wide reaching applications, from waste water purification to biodiesel production. We aim to design a system capable of producing micro algae in a cost effective, reliable, and efficient manner by utilizing an airlift style reactor design.

Specifications and Constraints

Specifications	**Target Value**	**Unit**
Min and Max Volume	**10-15**	**Gallons**
Minimal Energy Input	**N/A**	**Watts**
Incorporate Light System	**N/A**	**N/A**
Incorporate CO_2 Injection System	**N/A**	**N/A**
Forced Circulation System	**N/A**	**N/A**
Constraints	**Target Value**	**Unit**
Dimensions	**"Small"**	**ft**
Material Cost	**< 2000**	**$**

Updated Specifications and Constraints

Specifications	Target Value	Unit
Min and Max Volume	**10-20**	**Gallons**
Minimal Energy Input	**N/A**	Watts
Incorporate Light System	**N/A**	**N/A**
Incorporate CO_2 Injection System	**N/A**	**N/A**
Forced Circulation System	**N/A**	**N/A**
Materials	Aluminum/Acrylic	**N/A**
Constraints	**Target Value**	**Unit**
Dimensions	Under 6ft tall, small footprint	**ft**
Material Cost	**< 2000**	**$**
Weight	**< 300**	**lbs**

Deliverables

The following deliverables were chosen in a manner so that a similar PBR system could be replicated quickly and without undue interpretation by another project team. This team would also be able to continue testing from where the present team left off.

- Current PBR system
- Comprehensive final design report
- System schematics
- Bill of Materials (BOM) and list of expenditures

Due to time constraints and limitations, we were not able to complete testing on the reactor. Larger images of the system schematics, the BOM, and the code for the Arduino System are included in the appendices.

PROJECT PLAN

Roles and Responsibilities

Note: All team members share responsibility for every task, but one person is placed in charge of each role to keep that part of the group on track.

Budget: Lucas Becia

- Contact BE office for use of credit card.
- Get approval for big purchases and make sure all are tax exempt.

Client Contact: Samuel Funk

- Communicate with client and mentors on behalf of team.

Team Meetings: Matthew Jungert

- Draft and circulate agenda to group before meetings.

Team Documentation: Samuel Funk

- Keep meeting minutes at each meeting and the group portfolio up to date.

Modeling/ Building: Nathan Wiedenmeyer

- Draft a 3D Model of the design and run simulations before building the prototype.
- Fabricate the final prototype.

Wiki Page: Sage Pratt

- Builds and updates the group wikipage with information and pictures documenting the project.

Biological Engineering: Lucas Becia, Samuel Funk, Matthew Jungert

- The BEs in the group will handle the logistics of the Biological parts of the project.

Mechanical Engineering: Nathan Wiedenmeyer, Sage Pratt

- The MEs in the group will handle the logistics of the Mechanical parts of the project.

Future Roles: Group

Future roles that come up as the project progresses will be assigned by group discussion and agreement, most likely by whoever volunteers and is most competent.

DESIGN ALTERNATIVES

Concentric Tube Bubble Column: Internal Riser

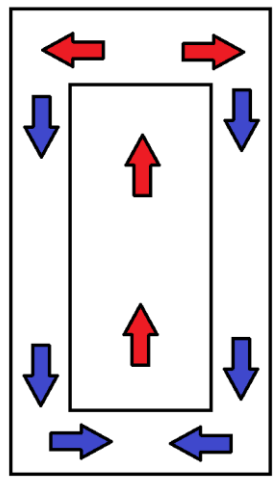


Figure 1: Internal Riser.

Concentric Tube Bubble Column: External Riser

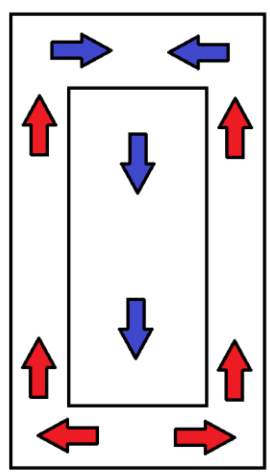


Figure 2: External Riser.

Baffle Separated Bubble Column

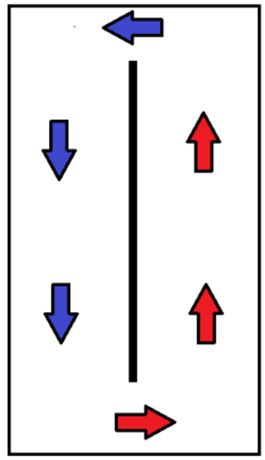


Figure 3: Baffle Separated.

External Loop Air-Lift Reactor

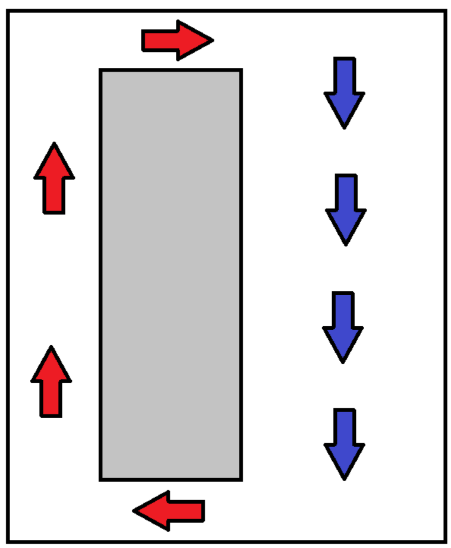


Figure 4: External Loop.

SOLUTION CONCEPT

Figure 5: PBR system assembly.

A concentric tube, bubble column, internal riser reactor was decided to be the best option for the design. The reactor provides ample circulation, adequate mixing intensities, exposes cells to low amounts of shear stress, operates with minimal input energy, and is relatively easy to assemble. A sensor system was also included with the reactor allowing for the measurement of pH within the Riser Tube and Downcomer Tube. An ORP sensor was also included as opposed to a dissolved CO_2 sensor due to budget constraints. A nutrient solution would be introduced into the reactor through the lid using a peristaltic pump. This pump could be calibrated to each specific algae strain desired to maximize efficiency. The light source for the reactor is provided by an LED tube array submerged within the reactor. RGB LEDs will be used to allow full light spectrum customization.

SYSTEM COMPONENTS

Plastic Machined Base

The machined base has a diameter of 10 in and a height of 2 in. The curve of the base was machined using a CNC Milling machine. This method was chosen to improve the accuracy and functionality of the piece. The base curvature is to improve the flow as it transitions into the Riser Tube as it exits the Downcomer Tube.

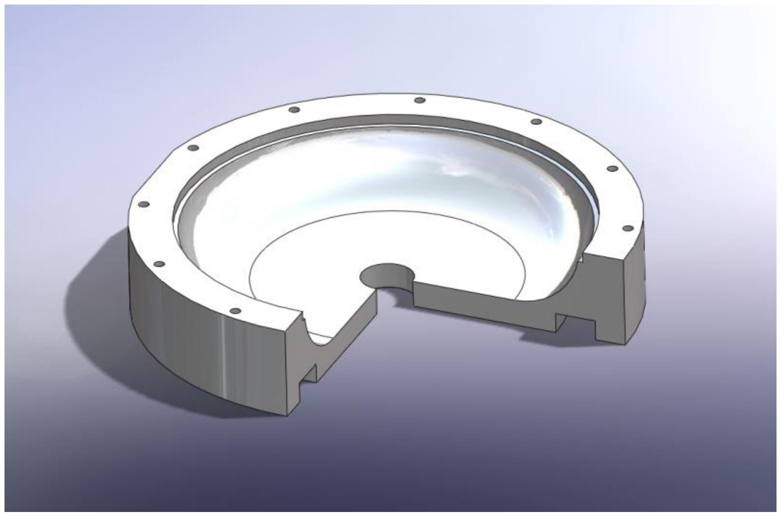


Figure 6: Plastic Machined Base.

Flange

The flange was constructed out of two distinct aluminum pieces. The first piece was the cylindrical connection, this piece was ordered and has an inner diameter of 10 in and a ¼ in thickness. The cylinder is welded to a ½ in thick plate. The plate was cut with a plasma cutter, and then treated with a grinder to have an inner diameter of 10 in.

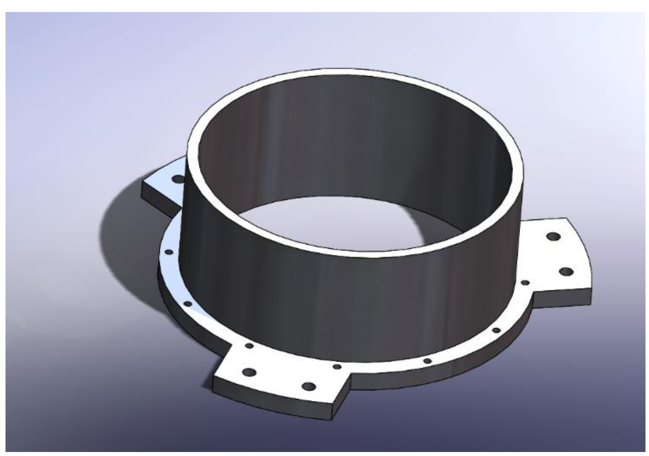


Figure 7: Flange.

Acrylic Downcomer Tube

The acrylic Downcomer tube had a length of 6 ft and an outer diameter of 10 in. Flow exits the riser tube and falls to the base through the Downcomer Tube where it then enters the bottom of the riser tube.

Acrylic Riser Tube

The Riser Tube has a length of 5 ft and an inner diameter of 6 in. The sparger sits in the base of the riser tube. Flow in the reactor enters at the base of the Riser Tube and exits at the top of the tube into the top of the Downcomer tube.

Riser Stabilizer Ring

The riser stabilizer ring keeps the riser tube from moving horizontally. The Riser Tube is surrounded by a 1/16 in thick, sheet steel, ring whos inner diameter is 6 in. Three 1 ½ in long quarter long bolts, located 120° apart from each other, protrude horizontally from the ring. The bolts are able to extend via twisting on screws welded to the ring so that they push on the interior of the Downcomer tube and keep the riser tube in place.

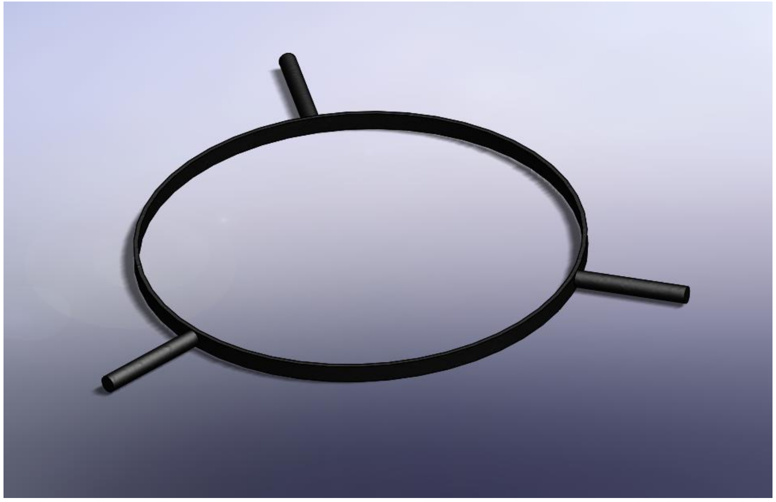


Figure 8: Riser Stabilizer Ring.

Riser Support Apparatus

The Riser Tube Support holds the base of the Riser Tube and keeps the tube stabilized in the vertical connection. The Riser Tube is sits on tabs protruding from the base of a 1/16 in thick, sheet steel, ring whose inner diameter is 6 in. Three 1 ½ in long quarter long bolts, located 120° apart from each other, protrude vertically from the ring.

Figure 9: Riser Support Apparatus.

LED Tubes

The LED tubes hold the LED strip light sticks. They are made from 1 ¼ inch diameter acrylic tube that are 5 feet long.

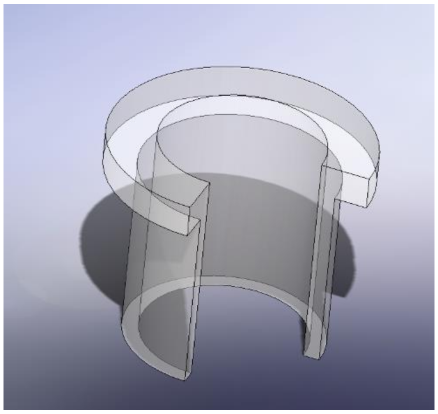


Figure 10: LED Tube Connection Pieces.

Figure 11: LED Tubes.

The LED Tube Connection pieces were machined out of cylinders of acrylic. The connection pieces have an inner diameter of **(SIZE)** and a total height of **(SIZE)**. The upper lip of each connection piece has an outer diameter of **(SIZE)**. The lower part of each connection piece encapsulates the LED Tubes, the have a height of **(SIZE)** and an outer diameter of **(SIZE)**.

Lid/LED Tube Holder

The lid sits on the top of the Downcomer Tube with step cut. Six holes with a diameter of **(SIZE)** circle the outside of the lid, a ¼ in in from the exterior of the lid. These holes hold the LED Tube connection pieces. A central hole with a diameter of **(SIZE)** sits in the middle of the lid. The central hole is for excess gas emission and tube insertion.

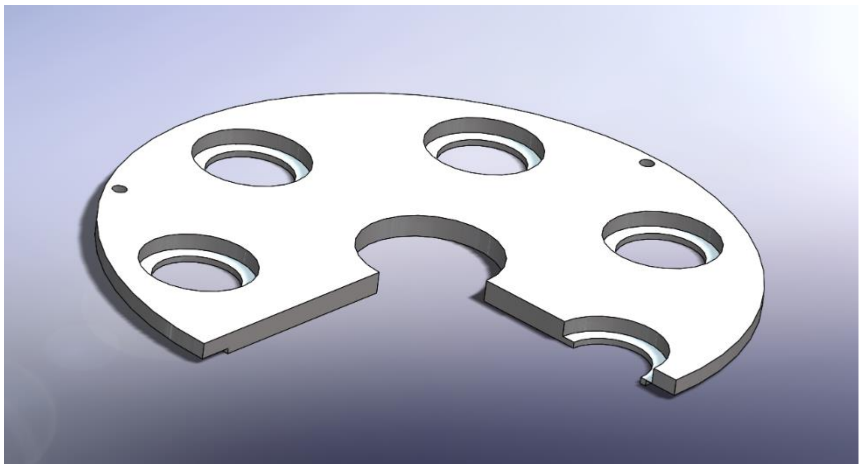


Figure 12: Lid/LED Tube Holder.

Sparger

The sparger is a 6 in diameter ring with a thickness of 1 in. The sparger sits in the base of the riser tube, gas is introduced into the reactor through the sparger which creates the bubbles that drive circulation throughout the reactor.

Figure 13: Sparger.

Reactor Leg Support

The support legs were made from 1 ½ wide flat bar steel. They we welded together and then painted for protection against wet environments. Two leveling feet were added to each of the three legs to provide support on uneven surfaces.

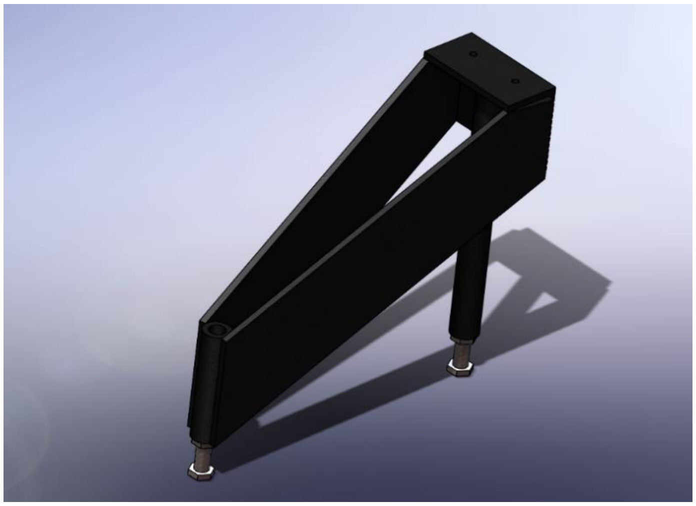


Figure 14: Reactor leg support.

Reactor Drainage System

The drainage system mounts under the plastic machined base. It is threaded into the base with 1-inch pipe thread. A ball valve is connected in line to control when the reactor is drained. The pipe and elbow are both made from 1-inch PVC.

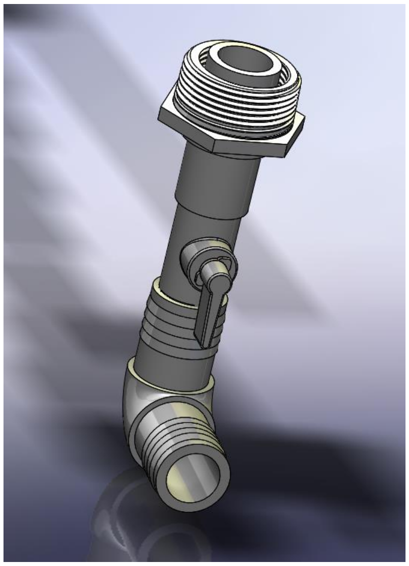


Figure 15: Reactor Drainage System

Sensor System

Figures 16 and 17 show the sensor setup. Using an Arduino Mega, two pH sensors and an ORP sensor are able to send readings to an LCD display to provide readings in real-time.

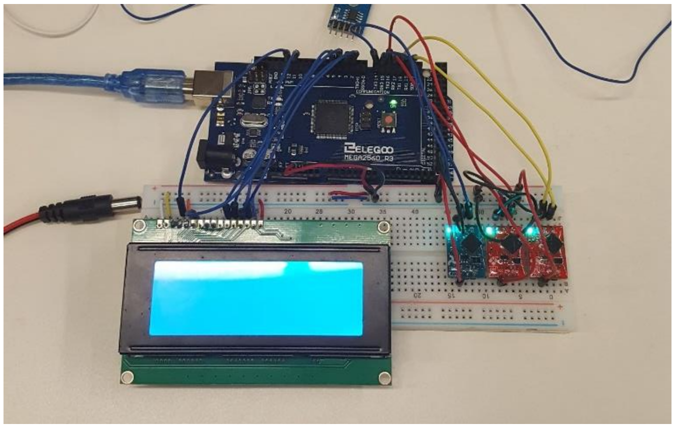


Figure 16: Sensor Setup

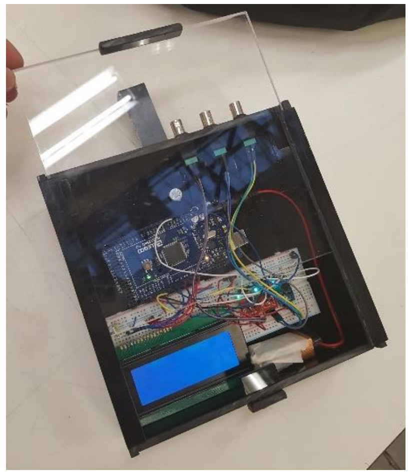


Figure 17: Sensor Housing Container.

DESIGN EVALUATION

Flow at Base

Figure 18 shows a simulation of flow exiting the Downcomer Tube and entering the Riser Tube.

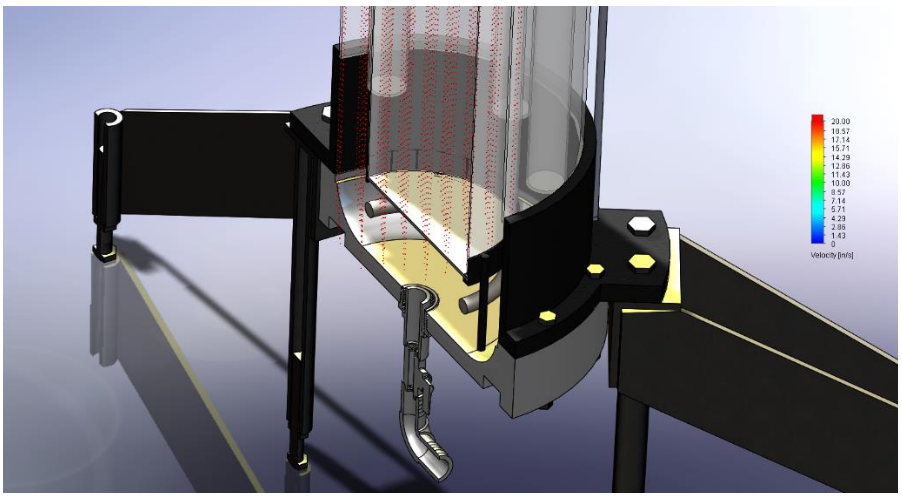


Figure 18: Image of an evaluation element.

Flow Through the Reactor

Figure 19 shows a simulation of flow in the Riser and Downcomer Tubes midway in the reactor.

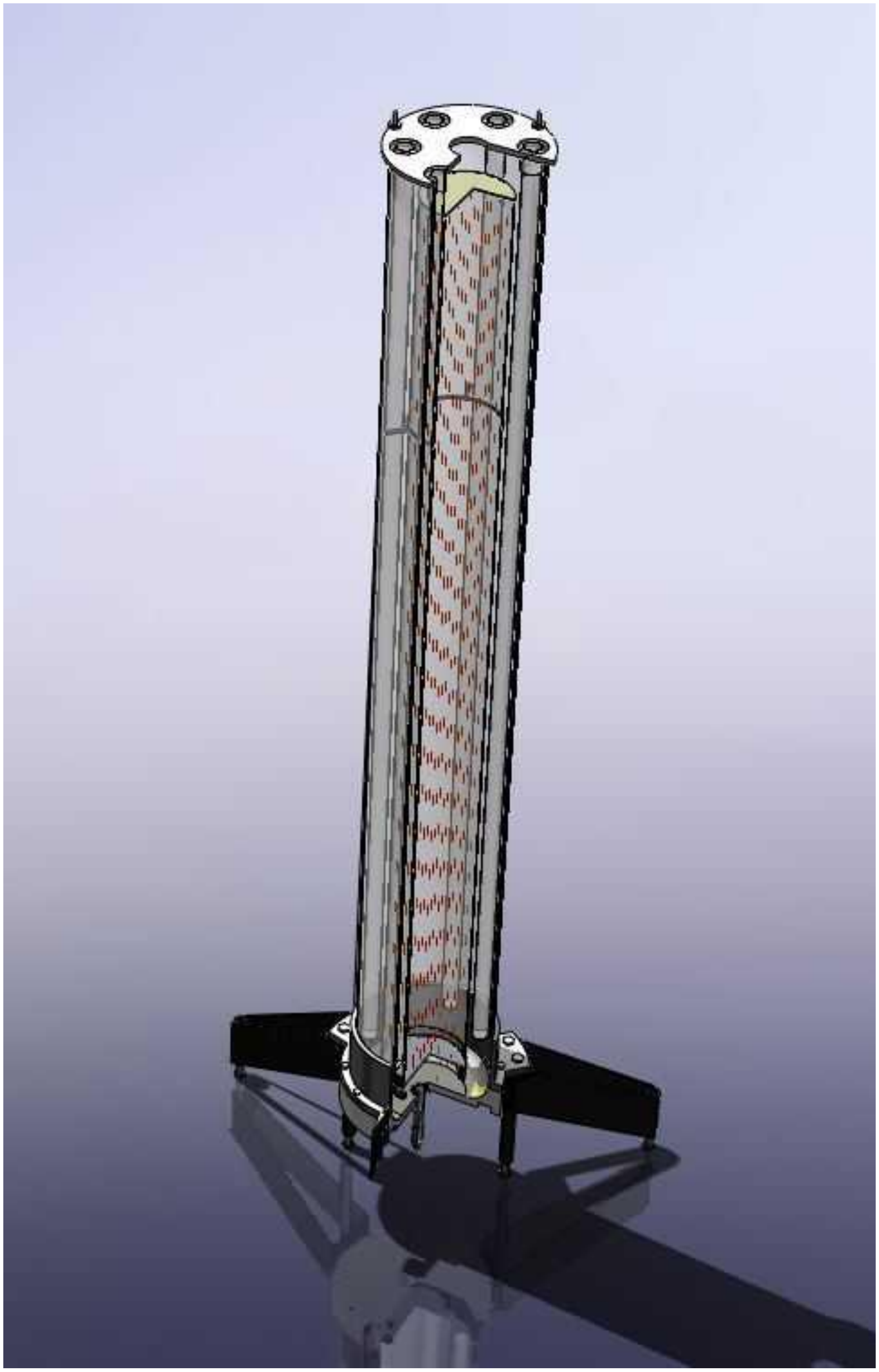


Figure 19: Reactor Flow.

Testing Procedures

No testing procedures were conducted due to time constraints. Below is a list of planned testing procedures that are needed to ensure proper function of the reactor.

Flow Testing:

Using a neutrally buoyant bead or other similar item, the flow speed can be measured by observing the time the bead takes to move a specific distance.

Sensor Testing:

The two pH sensors and the ORP sensor need to be calibrated. By obtaining solutions of know pH's, the sensors can be calibrated to show accurate values.

Algal Growth Test:

A sample of known algae species could be added to the reactor, and a life cycle growth test could be performed. This would reveal any unknown issues that could be solved before major research is conducted.

Results

No testing procedure results were obtained due to time constraints

CONCLUSIONS

Future Recommendations

Design Recommendations

Sparger Design

Rethink and design a better Sparger. With the current perforated tube design, bubbles do not flow evenly around the sparger ring. This causes uneven bubble sizes to ascend the riser tube, creating turbulent flow. A possible consideration is using aquarium air-stones set in a circular pattern within the riser or downcomer. Figure 20 shows a model of the potential design. The aquarium air-stones would provide consistent bubble size and increasing the number of stones in the array would increase the distribution.

Figure 21: Potential Sparger Design

Light System

Create a better lighting system with higher quality parts. We purchased LED light strip kits and created our light system based on the limitations of those kits. A better solution for the future would be to either invest in higher quality LED strip, or create dedicated LED boards that could be connected in a chain. The current setup is also controlled with an Infrared remote. This limits the customization of wavelength desired for algae production. A solution would be to program the LEDs with a microcontroller. This would allow specific wavelengths to be chosen, rather than pressing just by pressing a button on a remote.

Sensor System

Create a more permanent system for sensor controls. We chose to use hardware kits for the sensor controls due to the ease of use. They currently work well and perform as they should. It would be an improvement to attach the components more securely together. We used a solderless breadboard and connection wires to assemble it. Changing these out for a permanent solder board and connections would improve safety and make the system more durable.

APENDICIES

Appendix A: DFMEA

The following is a DFMEA analysis of the reactor. The analysis is on a scale of 1 – 10 where 1 is a low severity and 10 is high.

DFMEA

System:	Photobioreactor		**Prepared by:**	Samuel Funk
Design Team:	Uidaho PBR		**DFMEA Date:**	5/1/2018
Team Members:	Samuel Funk, Matthew Jungert, Sage Pratt, Luke Becia, Nate Wiedenmeyer		**Revision Date:**	

Item/Function	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Potential Failure causes/mechanisms	OCC	Current Design/Process Controls	DET	RPN	Recommended Action(s)
Plastic Machined Base	Seal leak	Drainage of Reactor	2	Gasket/Silicone Failure	1	Inspect seals prior and durring operation	1	2	install new Gasket/Silicone
Aluminum Flange	Seal leak	Drainage of Reactor	2	Gasket/Silicone Failure	1	Inspect seals prior and durring operation	1	2	install new Gasket/Silicone
	Bolt Failure	Drainage of Reactor	2	Overtightenign of Bolt pattern	1	tighten to 8 ft.lbs.	1	2	replace bolt
Reactor Downcomer/Riser	Seal leak	Drainage of Reactor	2	Silicone Failure	1	Inspect seals prior and durring operation	2	4	install new Silicone
	Crack/Shattering	Drainage of Reactor	10	Impact to reactor	2	Set up Reactor in isolated area	1	20	inform everyone in the area, put up hazzard warnings
LED Tubes	Seal leak	Flooding of Tube	8	Seal Failure	2	Inspect seals prior and durring operation	1	16	Improve sensor robustness
LED Ligh Sticks	Flooding	Electrocution Hazzard	10	LED Tube Seal Failure	2	Inspect seals prior and durring operation. Keep powered through GFCI outlet	1	20	Maintain clean work areas, Clean up water spills around reactor.
Lid/LED Tube Holder	Breaking/Deforming	LED Tube Falling into reactor	8	LED Tube System Failure	1	Inspect for unessisary items placed on rector.	1	8	Do not allow clutter to be placed on or near Reactor
Sensor Curcit	Electrical Short	Electrocution Hazzard	8	Water/Fall Damage	1	Inspect for water splash before and durring operation	2	16	Maintain clean work areas, Clean up water spills around reactor.
Reactor Leg Support	Tiping of Ractor	Catastrofic Failure	10	improper Foot leveling	1	Visual inspection before and during reactor operation	1	10	Always level reactor, and maintain a clean surrounding

Appendix B: Budget

The following depicts the budget used throughout the project. This includes an overall spent budget, and an itemized expenses report.

ENTER EXPENSES

PBR

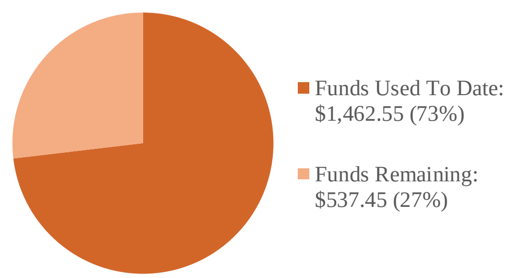
CONSTRUCTION BUDGET

PROJECT INFORMATION

Project Name	Photobioreactor
Project Description	The team designed and produced a bench-scale, internal-loop Photo Bioreactor (PBR) system for research purposes. The final product operates using minimal energy input per working volume and incorporates a light dispersion mechanism to maximize light utilization. The project is novel using only a carbon dioxide injection system for circulation.

FINANCIAL STATUS

Cash Amount	$2,000
Total Allotted Funds	$2,000
Funds Used To Date	$1,463
Funds Remaining	$537



BUDGET SUMMARY

LIST OF EXPENSES

PROJECT FUNDS ALLOTTED	FUNDS USED TO DATE	FUNDS REMAINING
$2,000.00	$1,462.55	$537.45

Item	Category	Amount
Outer Tube (10")	Tube	$399.22
Inner Tube (6")	Tube	$165.04
LED Tube (1.25") (6)	Tube	$102.64
RGB Strip Lights	Lights	$83.97
LED wooden sticks	Lights	$9.00
GFCI Power Strip	Lights	$28.94
Pre Made Flange	Base/Lid Material	$80.69
Arduino	Sensor/Circuits	$10.99
Jebao Programmable Auto Dosing Pump DP-4	Instruments	$63.00
pH Sensor (2)	Instruments	$160.00
Temperature Sensor	Instruments	$11.99
Micro Bubble Air Diffuser Ring, 6 In	Instruments	$23.63
ORP Sensor	Instruments	$108.00
54" Gas Hose	Fittings	$9.99
5/8"-18 inert gas fitting to 1/4"NPT adapter	Fittings	$4.18
Check Valve	Fittings	$2.00
Brass Coupling	Fittings	$2.76
1/4" NPT Male to 1/4" barb fitting	Fittings	$1.54
EZO pH Circuit (x2)	Sensor/Circuits	$80.00
Pre-Assembled Female BNC (x3)	Sensor/Circuits	$42.00
EZO ORP Circuit	Sensor/Circuits	$40.00
Arduino	Sensor/Circuits	$10.99
LCD Display (x2)	Sensor/Circuits	$21.98
Total		$1,462.55

Category

- Base/Lid Mat...
- Fittings
- Instruments
- Lights
- Sensor/Circuits

Appendix C: Arduino MEGA Code

The following is the Arduino MEGA code used to program the reactor's sensors.

```
//This code was written to be easy to understand.
//This code will output data to the LCD display.
//Type commands into the Arduino serial monitor to control the pH and ORP
circuits.


#include <LiquidCrystal.h>


LiquidCrystal lcd(1,2, 4, 5, 6, 7);

String inputstring = "";                                   //a string to hold
incoming data from the PC
String sensorstring = "";                                  //a string to hold the
data from the Atlas Scientific product

String sensorstring1 = "";
String sensorstring2 = "";
String sensorstring3 = "";

boolean input_string_complete = false;                     //have we received all
the data from the PC

boolean sensor_string_complete = false;


float pH;                                                  //used to hold a
floating point number that is the pH


void setup() {                                             //set up the hardware
                                                          //LCD display setup
  lcd.begin(20,4);
  lcd.setCursor(0,0);
  lcd.print("Riser pH:");
  lcd.setCursor(0,1);
  lcd.print("Downcomer pH:");
  lcd.setCursor(0,2);
  lcd.print("ORP:");


  Serial3.begin(9600);                                     //set baud rate for
software serial ports 3, 2, and 1 to 9600
  Serial2.begin(9600);
  Serial1.begin(9600);

  inputstring.reserve(10);                                 //set aside some bytes
for receiving data from the PC
  sensorstring.reserve(30);                                //set aside some bytes
for receiving data from Atlas Scientific product
  delay(500);
}
```

```
void serialEvent() {                                   //if the hardware
serial port_0 receives a char
  inputstring = Serial.readStringUntil(13);            //read the string until
we see a <CR>
  input_string_complete = true;                        //set the flag used to
tell if we have received a completed string from the PC
}


void serialEvent3() {                                  //if the hardware
serial port_3 receives a char
  sensorstring3 = Serial3.readStringUntil(13);          //read the string
until we see a <CR>
  sensor_string_complete = true;                       //set the flag used to
tell if we have received a completed string from the PC
}

void serialEvent2() {                                  //if the hardware
serial port_2 receives a char
  sensorstring2 = Serial2.readStringUntil(13);          //read the string
until we see a <CR>
  sensor_string_complete = true;                       //set the flag used to
tell if we have received a completed string from the PC
}

void serialEvent1() {                                  //if the hardware
serial port_1 receives a char
  sensorstring1 = Serial1.readStringUntil(13);          //read the string
until we see a <CR>
  sensor_string_complete = true;                       //set the flag used to
tell if we have received a completed string from the PC
}

void loop() {                                          //here we go...


  if (input_string_complete == true) {                 //if a string from the
PC has been received in its entirety

    Serial3.print(inputstring);                        //send that string to
the Atlas Scientific product
    Serial3.print("\r");                               //add a <CR> to the end
of the string
    inputstring = "";                                  //clear the string
    input_string_complete = false;                     //reset the flag used
to tell if we have received a completed string from the PC
    }

          if (sensor_string_complete == true) {                //if a string
from the Atlas Scientific product has been received in its entirety
           Serial.print("ph Riser:");
           Serial.print(sensorstring3);                       //send that
string to the PC's serial monitor
           lcd.setCursor(14,0);
           lcd.print(sensorstring3);
           }
```

```
  if (input_string_complete == true) {                //if a string from the
PC has been received in its entirety
    Serial2.print(inputstring);                       //send that string to
the Atlas Scientific product
    Serial2.print("\r");                              //add a <CR> to the end
of the string
    inputstring = "";                                 //clear the string
    input_string_complete = false;                    //reset the flag used
to tell if we have received a completed string from the PC
    }
           if (sensor_string_complete == true) {               //if a string
from the Atlas Scientific product has been received in its entirety
           Serial.print("       ph Downcomer:");
           Serial.println(sensorstring2);       //send that string to the
PC's serial monitor
           lcd.setCursor(14,1);
           lcd.print(sensorstring2);

           }

  if (input_string_complete == true) {                //if a string from the
PC has been received in its entirety
    Serial1.print(inputstring);                       //send that string to
the Atlas Scientific product
    Serial1.print("\r");                              //add a <CR> to the end
of the string
    inputstring = "";                                 //clear the string
    input_string_complete = false;                    //reset the flag used
to tell if we have received a completed string from the PC
    }
        if (sensor_string_complete == true) {      //if a string from the
      Atlas Scientific product has been received in its entirety
           Serial.print("                                                 O
RP:");
            Serial.println(sensorstring1);            //send that string to
                                                      the PC's serial monitor
           lcd.setCursor(14,2);
           lcd.print(sensorstring1);
           }

  sensorstring = "";                                  //clear the string:
  sensor_string_complete = false;                     //reset the flag used
to tell if we have received a completed string from the Atlas Scientific
product

         }
```

Appendix D: Gantt Chart

Due to size constraints, the Gantt Chart may be viewed at this link:

Gantt Chart Link