Northumbria University
NEWCASTLE

Development of a Photobioreactor system for microalgae cultivation, lipid extraction and biofuel production

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Project Description

To develop a photobioreactor system that has the capacity for accelerated algae growth and oil extraction within a closed tubular system. The system will be able to maintain optimal conditions of water to accelerate growth rate.

Objectives

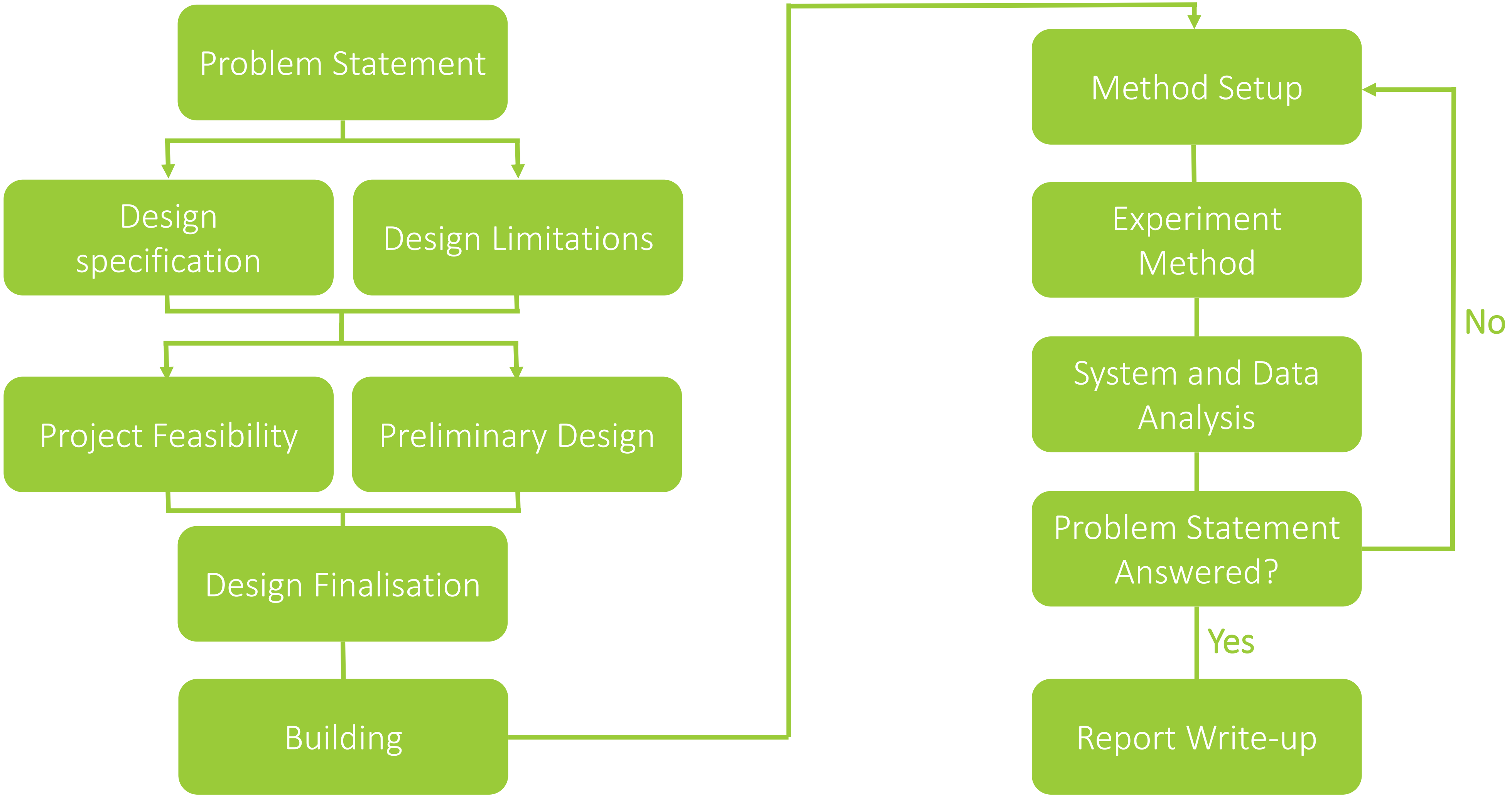
1) To develop a design for a closed cultivation system to promote algae growth and lipid oil production.
2) Produce working Photobioreactor system from designs.
3) Lipids should be processed into useable Bio-fuel.
4) Bio-fuel produced must meet a set standard for energy content.
5) Investigate the optimal growth conditions for a closed system to maximise useful oil production.

Module Learning Outcomes

EN0751 has a set of learning outcomes or project criteria that need to be achieved, this is how our group aim to meet ours;

- **MLO 1 – Designing and building an affordable system for bio-fuel production.**
- **MLO 2 – Design to production stage of a full system for the fabrication of alternative fuels in the inevitability of fossil fuels running out. This topic could be expanded to discuss social and environmental impacts of the technology.**
- **MOL 3 – Demonstrated through the technical drawings of designs. Even after this, experimental methods must be used to select algae and water conditions best suited for the system.**
- **MLO 4 – The system design will include mechanical and electrical systems to become automated. Collaboration is required between many disciplines to produce a prototype.**
- **MLO 5 – Building material, part and consumable resource cost analysis will be implemented to ensure the project will not over budget. Regularly scheduled Bi-weekly meetings to further develop project goals and achieve outcomes.**

Experimental Methodology



Project Timeline

	Nov '18	Dec '18	Jan '19	Feb '19	Mar '19	Apr '19	May '19
System design							
Order & receive							
Build							
Optimise Design							
Grow algae							
Process data							
Presentation & Reflection							

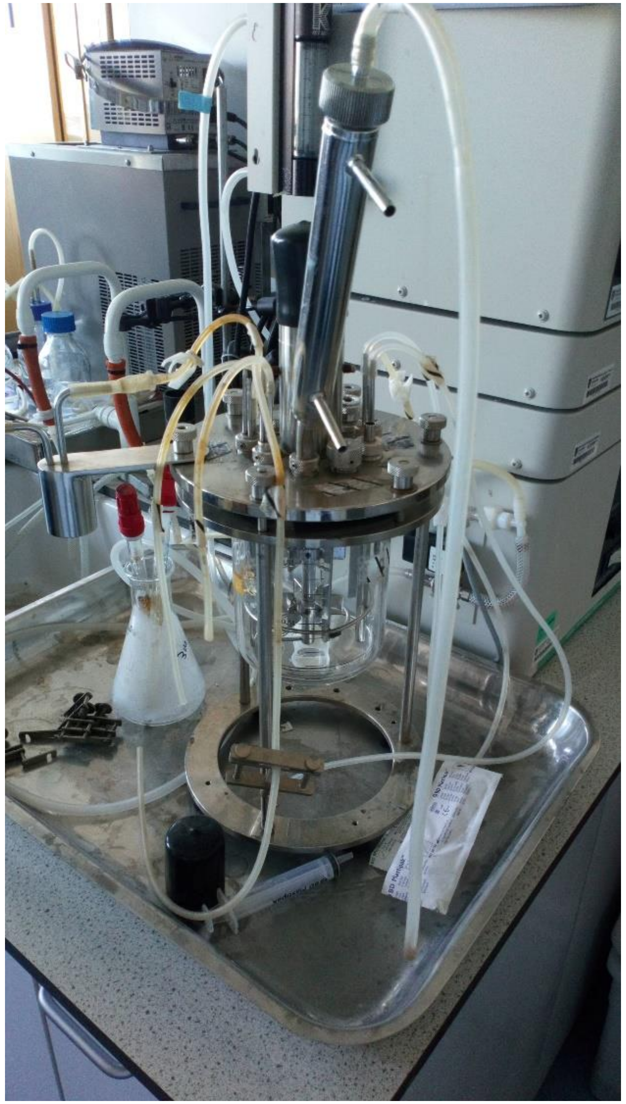
Early November visit from Dr. Hernandez

- In early November of 2018 Dr. Hector Hernandez arrived to share his expertise in his field and the relevance it had to this project.

- Throughout meetings and a project presentation, critiques and adjustments were made to our designs. These critiques were specialised to our project field and invaluable general advice about project management skills.

- The insights from Dr. Hernandez were critical to the development of the bioreactor we have co

Northumbria University Applied Sciences Photobioreactor



- Uses 1L to 10L reactors.
- Has a highly sterilised environment.
- Highly controllable conditions.
- Able to take samples without risking contamination through siphoning system.
- Only uses natural light, is not concerned with aspects of manipulated light cycles, light intensity or colour.

Northumbria University Engineering Photobioreactor

- 24 lots of 1.5L bottles.
- Less controllable environment
- ‘Control Bottle’ with pH probe controls CO2 input.
- Culture density measured through taking Optical density readings of samples.
- Able to regulate CO_2 input through system rig.

Literature Review Topics

An overview of the required reading to progress the project beyond concept

Light System Design

- Reflective materials used on the sides of the light Camber to maximize incidence.
- Bulb type (LED/ Incandescent/ fluorescent) and intensity.
- Power supply/rigging.

Cultivation Conditions

- Fresh water *Chlorella Vulgaris* is used for initial microalgae
- PH and CO_2 level regulation through CO_2 injection, O_2 gas released with fermentation airlock valves.
- Sterilized system for each yield.

Transesterification

- The process of converting the lipid, produced from the system, into esters.

	Stoichiometric	Typical
Fat or Oil	100 lbs	100 lbs
+		
Alcohol [Methanol]	10 lbs	16-20 lbs
+		
Catalyst [NaOH; 1% w/w oil]	1 lb	1 lb
↓		
Biodiesel [Methyl Ester]	100 lbs	100 lbs
+		
Glycerin	10 lbs	10 lbs

Purification

- Tanks are sterilised in HNO_3 and rinsed with UHQ water.
- Algae growth medium is distilled water, Potassium Carbonate and 10% miracle grow. Then autoclaved.
- Miracle grow; Nitrogen 24%, phosphorous 8%, potassium 16%.

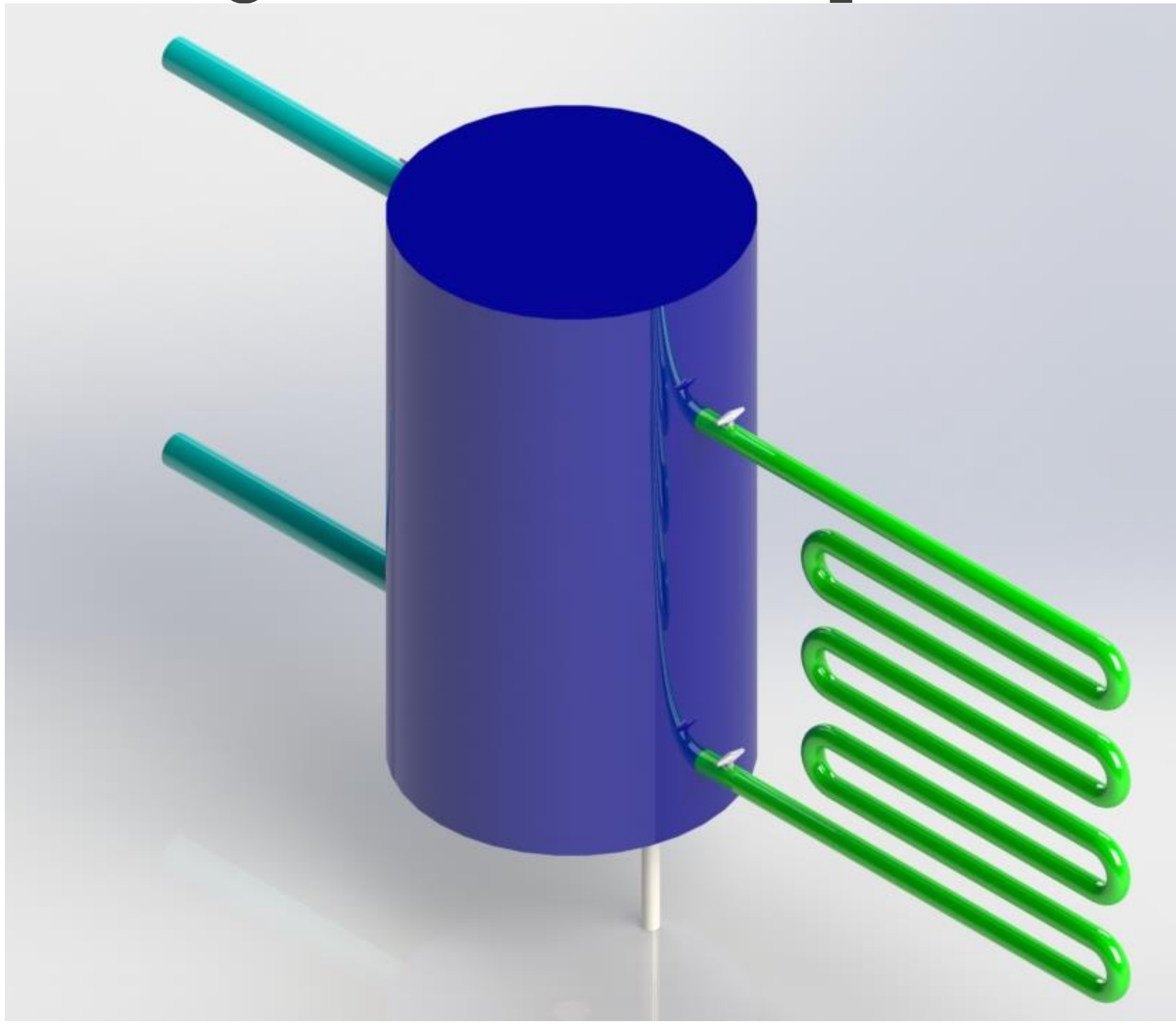
Automation System Design

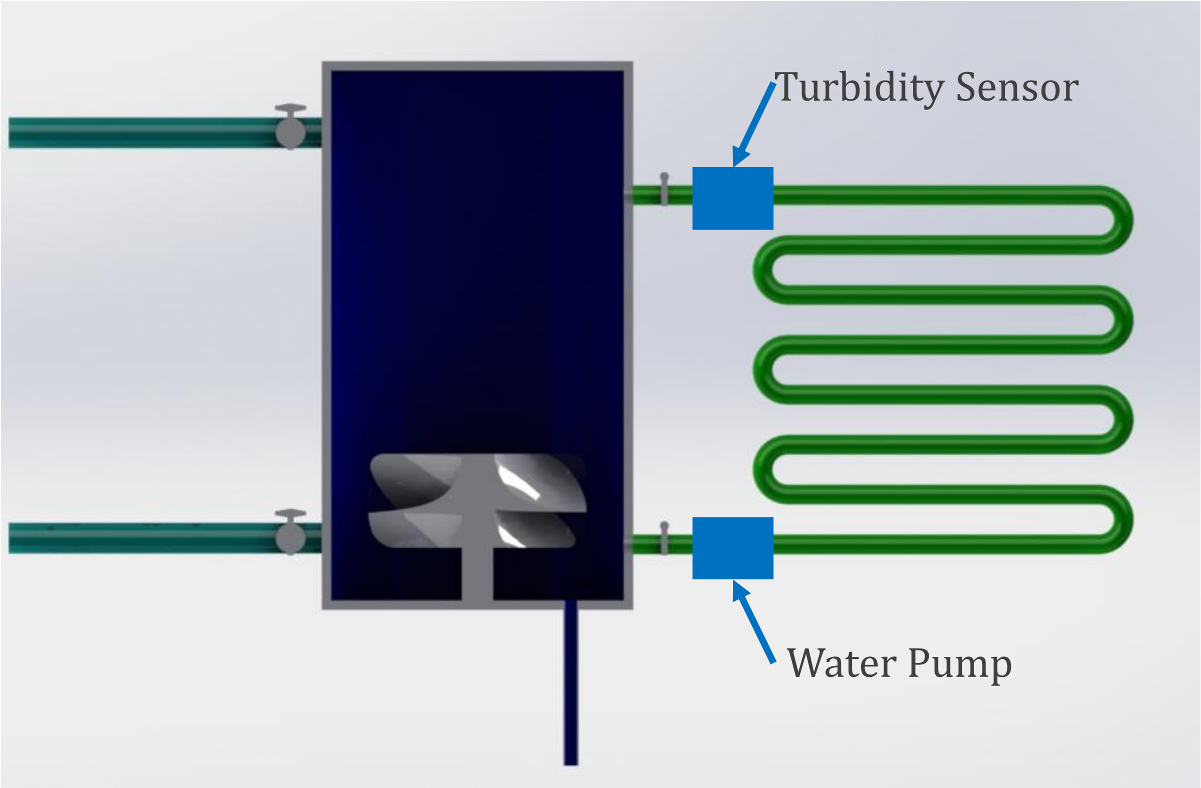
- Mini controlled system of sensors and actuators to automate system.
- Sensors; PH sensors and readers and thermocouples.
- Actuators; Solenoid valves.
- Designed to regulate own pH levels.

Algae Extraction Design

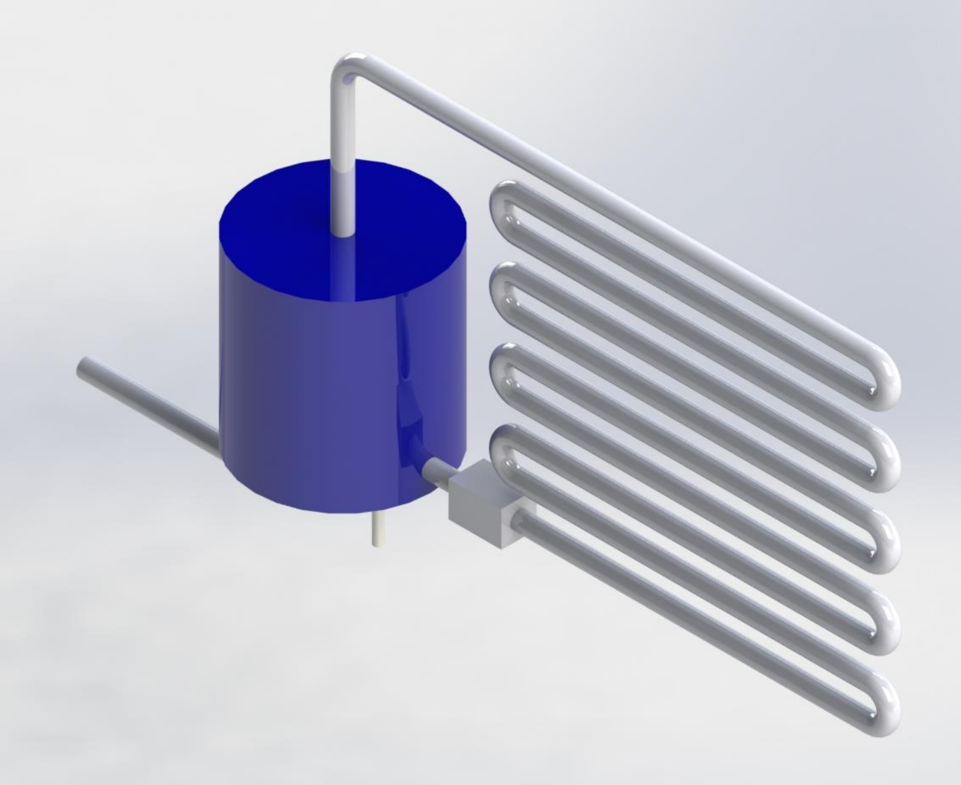
- Reverse Osmosis Crossflow Permeable Membrane, to extract water from algae medium.
- Pond pump is being used to channel water through the filter and back into the tank repeatedly.

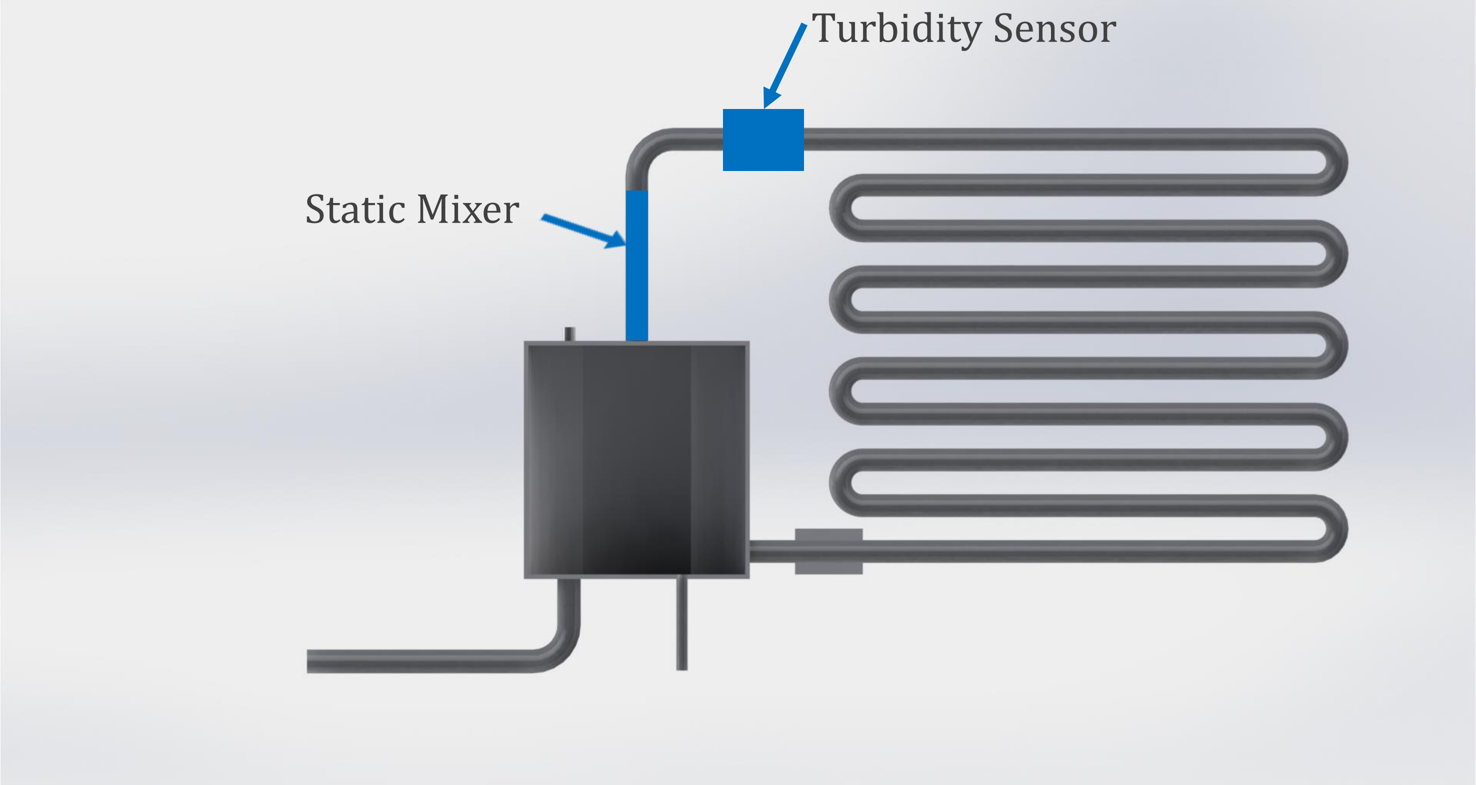
Design- initial concept





Design- updated initial concept





<u>Main changes to design</u>

- Reduced Size of Dark tank for increased light reactor volume proportionality.
- Installed more accurate dimensions based on material able to be bought in.
- More realistic ideas of water pump/light reactor design, taking on board head and pressure drop through Bernoulli's equation.
- Streamlined purging system and carbon dioxide delivery process, inline with realistic local buying options.

Design- 2nd concept

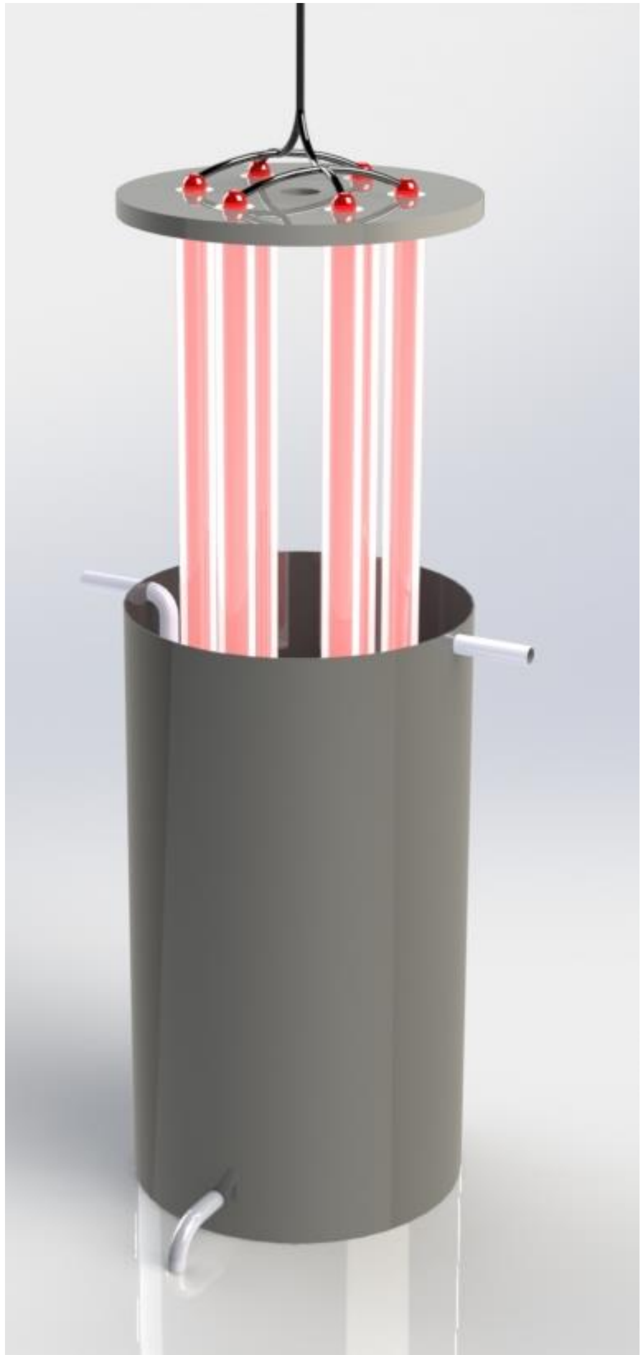
After discussing the initial design the system was deemed to complex (expensive and time consuming).

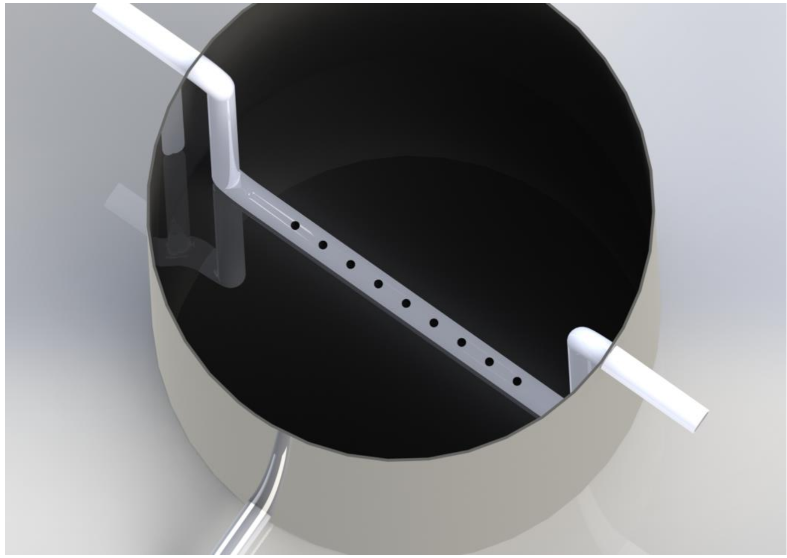
Design reasoning-

- A vertical bioreactor design was deemed best
- One large tank seemed simpler than multiple tanks to achieve 100L target
- Lights sealed and submerged hence removing need for an external cupboard and transparent tank
- CO2 and oxygen can be pumped in from the sides and bubbles up (no need to drill into the sides of the tank)
- Tap at bottom of tank to release final algae sludge

Evaluation of design-

- Large tank makes it harder to control contamination
- More difficult to experiment with one large tank
- IP testing for submerged lights is very stringent

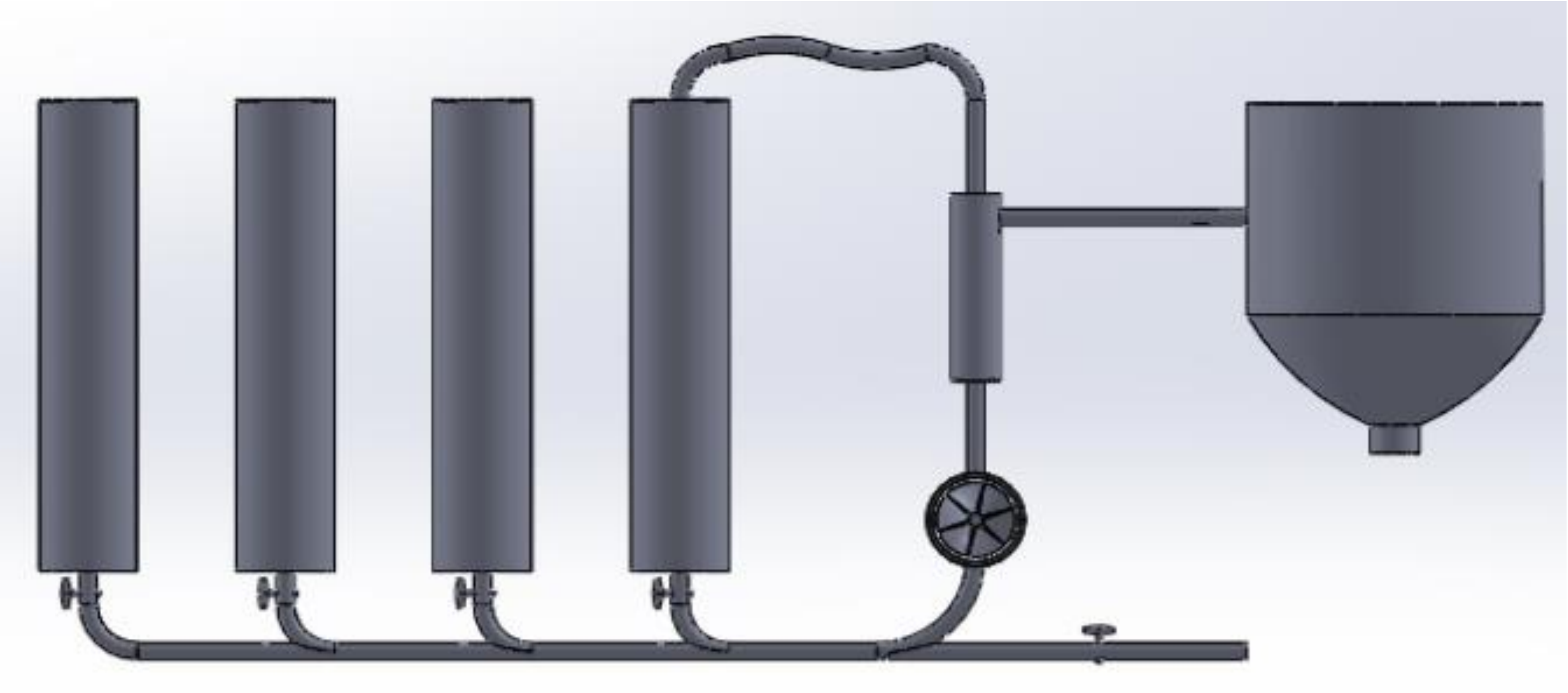




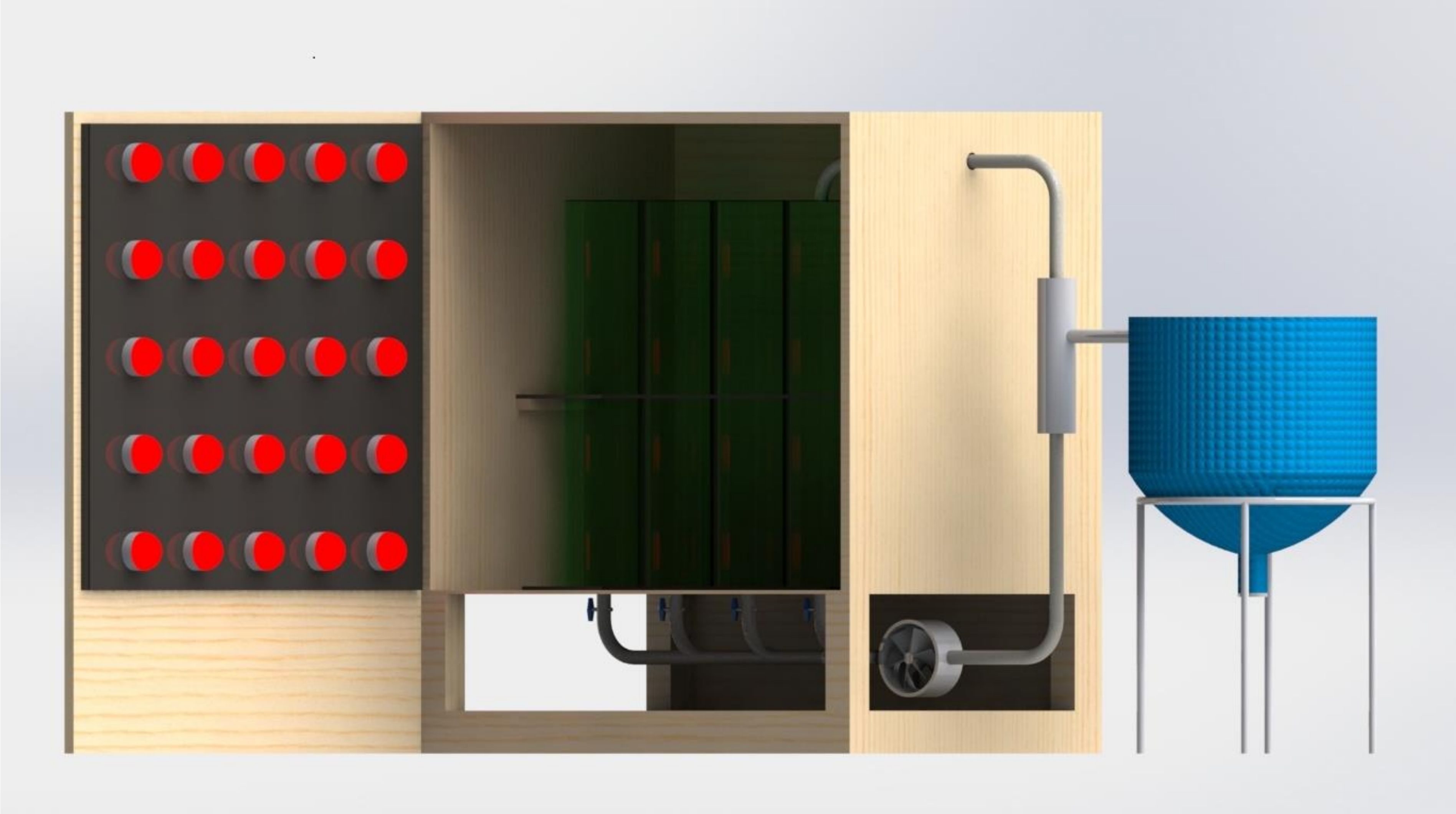
Design- 3rd concept

The issues with the last designs were brought to our attention by Dr. Hector Hernandez.

- A vertical bioreactor design was retained
- Multiple tanks allows for experimentation and control of contamination
- External light system for safety reasons
- CO_2 and oxygen can be pumped in the top of the tanks through plastic tubing which is cheaper than metal pipes
- Tap at bottom of each tank allows each to be individually filtered and drained
- Design shows the filtration system more clearly



Design- Final Render



Material/Parts list

		Item Name/Description	Quantity	Unit Cost (£)	Cost (£)	P&P (£)	Total Cost	Website	Order Date	Expected Arrival	Paid By
PBR	Light Reactor	Clear Piping	3	75	225	12.5	237.5	http://www.norplast.co.uk/#produ	05/12/18	02/01/2019	Tom
		Algae Sample (50ml)	5	8.75	43.75	6.4	50.15	https://www.sciento.co.uk/catalog/	//		Tom
		Bungs (2 pack)	2	4.79	9.58	0	9.58		//		Tom
					0	0	0		//		
	Lighting	Lights (6 pack)	2	15.99	31.98	0	31.98	https://www.amazon.co.uk/Lightin	//		Michael
		Light Fittings (20 pack)	1	8.46	8.46	0	8.46	https://www.amazon.co.uk/EVoluti	//		Michael
		Transformer	1	8.99	8.99	0	8.99	https://www.lightbulbs-direct.com/	//		Michael
		Plug Timer (pack of 4)	1	13.92	13.92	0	13.92	https://www.amazon.co.uk/gp/pro	04/12/18	08/12/2018	Katie
							0		//		
	Sensor Systems	pH Controller (Converted from €)	1	90.99	90.99	13.78	104.77	https://top-messtechnik.com/PH-C	//		Katie
		pH Meter	3	26.68	80.04	0	80.04	https://www.amazon.co.uk/Tempe	21/12/18		Katie
							0		//		
	CO2 System	CO_2 Diffuser	12	2.01	24.12	0.99	25.11	https://www.ebay.co.uk/itm/Aqua	04/12/18	22/01/2019	Katie
		Servo Valve	1	48.32	48.32	0	48.32		//		Katie
		8mm OD Hose (2m Sample)	1	0	0	13.24	13.24	http://pneumax.co.uk/wp-content/	01/03/19		Tom
		6mm OD Hose (25m)	1	11	11	0	11	http://pneumax.co.uk/wp-content/	01/03/19		Tom
		8mm-4mm fitting	1	1.2	1.2	0	1.2	http://pneumax.co.uk/wp-content/	01/03/19		Tom
		6mm Equal Tees	3	1.04	3.12	0	3.12	http://pneumax.co.uk/wp-content/	01/03/19		Tom
		6mm Straight Connector	12	0.83	9.96	0	9.96	http://pneumax.co.uk/wp-content/	01/03/19		Tom
		6mm Equal Cross Fitting	4	2.09	8.36	0	8.36	http://pneumax.co.uk/wp-content/	01/03/19		Tom
					0	0	0		//		
	Light Reactor Housing	Cupboard	1	60	60	35	95	https://www.diy.com/departments	//		Tom
		Boards	2	0	0	0	0		//		
		Light Reflective Material (arrived late)	3	1.64	4.92	1	5.92	https://www.amazon.co.uk/Reflect	//		Katie
		Light Reflective Material 2	2	7.79	15.58	0	15.58				
		Wheels	4	5.47	21.88	0	21.88	https://www.diy.com/departments	23/11/18	28/12/2018	Katie
		Perspex	1	79.12	79.12	14	93.12				Chris
		Nuts, Bolts, Screws, etc	0	0	0	0	0		//		
Filtration System	Filtration System	Straight Pipe (3m)	1	3.89	3.89	0	3.89	https://www.screwfix.com/p/flopla	04/12/18	06/12/2018	Katie
		Straight Pipe Tees	5	1.16	5.8	0	5.8	https://www.screwfix.com/p/flopla	04/12/18	06/12/2018	Katie
		25mm ID Hose (per meter)	2.5	4.1	10.25		10.25	https://www.advancedfluidsolution	//		
		19mm ID Hose (per meter)	0.5	4.1	2.05		2.05	https://www.advancedfluidsolution	//		
		Hose-Thread Fitting	2	2.08	4.16		4.16	https://www.advancedfluidsolution	//		
		Corner Pipes	3	1.19	3.57	0	3.57	https://www.screwfix.com/p/flopla	04/12/18	06/12/2018	Katie
		Pipe Taps	5	11.45	57.25	0	57.25		//		Katie
		Pipe clips (pack of 20)	1	6.99	6.99	0	6.99	https://www.screwfix.com/p/flopla	04/12/18	06/12/2018	Katie
		Pump	1	23.99	23.99	2.99	26.98	https://www.amazon.co.uk/nonmo	//		Tom
		Filter	1	24.96	24.96	0	24.96		//		Chris
		Filter Housing (converted from USD)	1	9.96	9.96	4.07	14.03		//		Chris
		Extendable Connector Hose (36.5mm)	1	7.55	7.55	0	7.55		//		Katie
							0		//		
							0		//		
Misc	Misc	20mm O Rings (pack of 20)?	0	1.41	0	0	0	https://www.amazon.co.uk/Rubbe	//		
		35mm O Rings (pack of 10) ?	0	3.14	0	0	0	https://www.amazon.co.uk/Black-F	//		
		190mm O Rings	0	5.65	0	0	0	https://www.amazon.co.uk/Sourcin	//		
		32mm View Pipe	0	31.62	0		0	https://www.amazon.co.uk/Global	//		
					0		0		//		

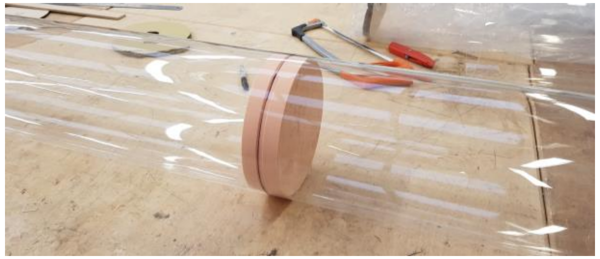
Total Parts Cost	P&P Costs	**Total Cost (£):**
960.71	103.97	1064.68

- A completed list of parts and carriage for all resources involved in the project.
- It was found that due to lead time constraints, some items became redundant as changing the design of the Bioreactor worked out best for cost and time.
- The total cost has exceeded the maximum budget, although buying the cheapest suitable option was taken, the project required changes based on project constraints.
- £1064.68 has been spent on goods and services.

Project Timeline

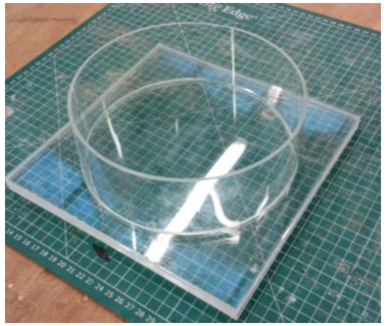
	Week Beginning	Delegation	04/02/2019	11/02/2019	18/02/2019	25/02/2019	04/03/2019	11/03/2019	18/03/2019	25/03/2019	01/04/2019	08/04/2019	15/04/2019	22/04/2019	29/04/2019	06/05/2019	13/05/2019
Module Deadlines	Individual Written Reflection 1	All	8	7	6	5	4	3	2	1	0				2	1	0
	Technical Report Deadline	All															
	Group Presentation Deadline	All															
	Peer and Self-Assessment	All															
	Individual Written Reflection 2	All															
Building Deadlines	Construction of Cabinet	All	X	X	X												
	Construction of PBR	All	X	X	X												
	Sensor Installation	All															
	Light Installation	All		X	X	X											
	CO_2 System Installation	All			X	X											
	Filtration System Construction	All															
	Sensor Calibration	All															
Algal Test Deadlines	PBR Cleansing	All			X												
	Algae Batch 1 & 2 Growth	All			X	X											
	Batch 1 & 2 De-watering	All															
	Batch 1 & 2 Testing	All			X	X											
	PBR Cleansing	All											Easter Break				
	Algae Batch 3 & 4 Growth	All															
	Batch 3 & 4 De-watering	All															
	Batch 3 & 4 Testing	All															
	PBR Cleansing	All															
Group Technical Report Deadlines	Introduction	All															
	Literature Review	All															
	Methodology	All															
	Results	All		**(Building)**					**(Testing)**								
	Discussion	All															
	Future Work	All															
	Conclusion	All															
	Abstract	All															
Group Presentation Deadlines	Consider Content	All															
	Create PPT	All															
	Practise Run-Throughs	All															

Construction



1 – The Tanks were cut to length to be 1m in height.

2 – The Bases are cut from 6mm acrylic.



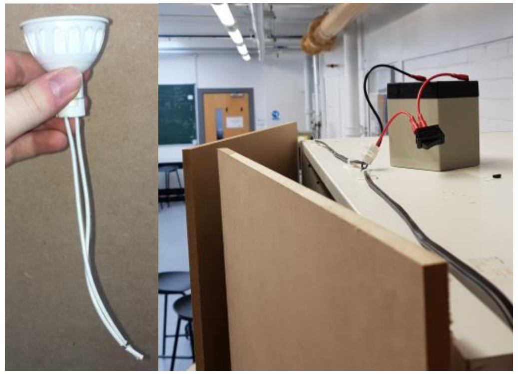
3 – The sheets are assembled into the base

4 – Assembly of the base to the tank walls.

5 – IP68 submersion test for suitability around lighting system.

6 – Assembled PBR housing

7 – 4 tank array fitted into PBR housing



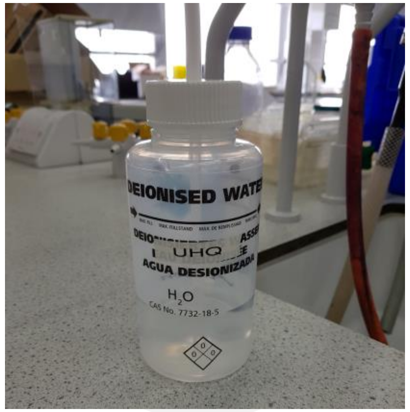
8 – Lighting system rigged and powered (Temporarily)

9 – Lighting System fitted to the housing

Construction (Current Stage)

- Fitting the reflective Mylar sheets to the walls was the last step completed.
- This week the following is being finalised and fitted; CO_2 rig, pH sensor and readout system, Automating the CO_2 intake through pH control and Extraction system.

Sterilisation and preparation


Tank preparation

- Tanks separated from PBR and rinsed.

Nitric Acid bath

- Nitric acid at 1% concentration is left to sterilise the bottles for an hour.

UHQ water rinsing

- UHQ deionised water was used to rinse the acid from the bottles before being sealed.

Initial algae supply

- 200 mL of algae is bough to be introduced to the reactor to upscale for the larger yield PBR.

Autoclaved Growth Medium

- The 1% concentration miracle grow to distilled water solution for growth medium is sterilised.

Testing

Algae 1% Mixture

- 10mL of Algae is introduced per 1 Litre of growth medium.

System regulation and calibration

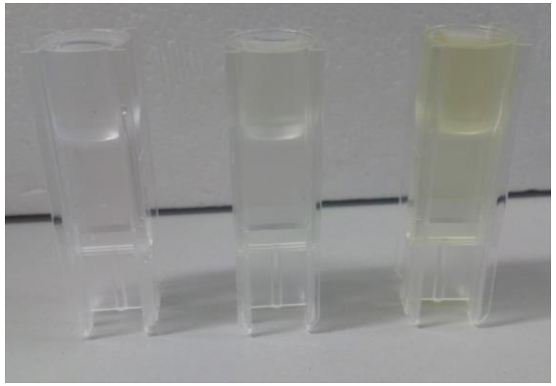
- pH calibration is used to optimise growth yield and quality.

PBR fitting

- Loading the bottles into the reactor, on a 16:8 Light/Dark cycle.

System Monitoring

Monitoring the pH readout values for system maintenance.

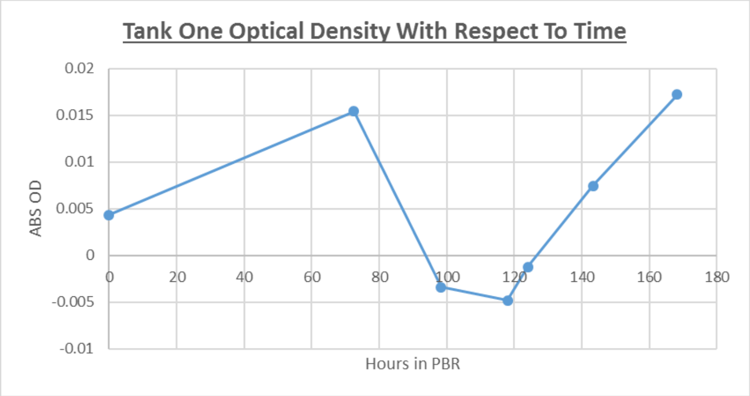


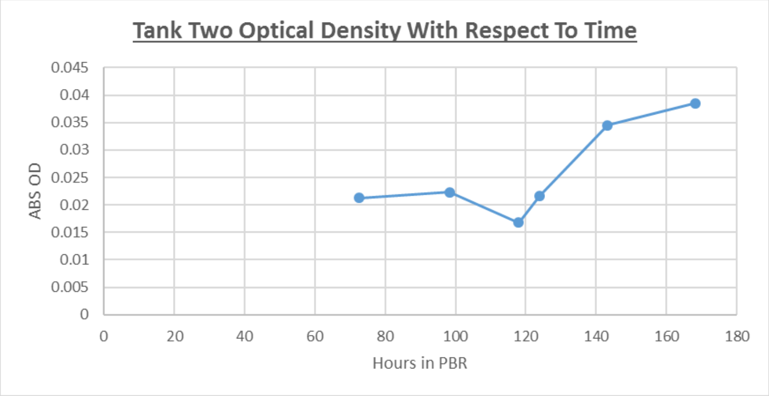
Growth Results

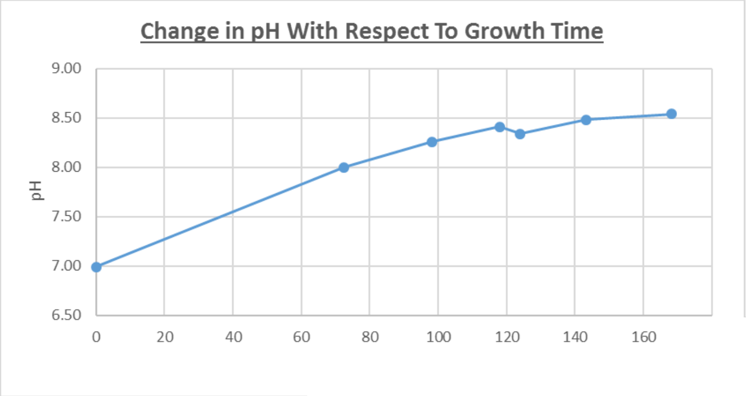
Daily result taking for growth tracking and avoiding population stagnation and culture death.

Results

Spectrophometry Test Results					λ = 625 nm									
	Initial Values													
Date	22/02/2019	22/02/2019	25/02/2019	25/02/2019	26/02/2019	26/02/2019	27/02/2019	27/02/2019	27/02/2019	27/02/2018	28/02/2019	28/02/2019	01/03/2019	01/03/2019
pH	6.99		8.00		8.26		8.41		8.34		8.48		8.54	
Time	1400		1430		1645		1030		1630		945		1045	
Hours In	0	0	72.5	72.5	98.25	98.25	118	118	124	124	143.25	143.25	168.25	168.25
Tank	1 (1L)	7 (500mL)	1	2	1	2	1	2	1	2	1	2	1	2
1st	0.0020	0.0040	0.0130	0.0170	-0.0060	0.0180	-0.0090	0.0130	-0.0030	0.0180	0.0040	0.0280	0.0120	0.0320
2nd	0.0050	0.0050	0.0130	0.0190	-0.0040	0.0210	-0.0060	0.0150	-0.0010	0.0170	0.0040	0.0300	0.0130	0.0330
3rd	0.0060	0.0060	0.0150	0.0210	-0.0020	0.0220	-0.0060	0.0160	-0.0020	0.0180	0.0060	0.0310	0.0150	0.0340
4th			0.0160	0.0220	-0.0030	0.0230	-0.0060	0.0170	-0.0010	0.0190	0.0060	0.0310	0.0150	0.0350
5th			0.0170	0.0220	-0.0020	0.0240	-0.0050	0.0170	-0.0010	0.0200	0.0070	0.0310	0.0160	0.0360
6th			0.0170	0.0230		0.0240	-0.0040	0.0180	-0.0010	0.0210	0.0070	0.0310	0.0160	0.0350
7th			0.0170	0.0230		0.0240	-0.0030	0.0180	-0.0010	0.0210	0.0080	0.0320	0.0170	0.0350
8th				0.0230			-0.0030	0.0190	0.0010	0.0200	0.0090	0.0320	0.0170	0.0350
9th							-0.0030	0.0180	-0.0010	0.0210	0.0080	0.0330	0.0170	0.0360
10th							-0.0030		-0.0010	0.0200	0.0080	0.0320	0.0170	0.0360
AVE	0.0043	0.0050	0.0154	0.0213	-0.0034	0.0223	-0.0048	0.0168	-0.0012	0.0217	0.0074	0.0346	0.0172	0.0386

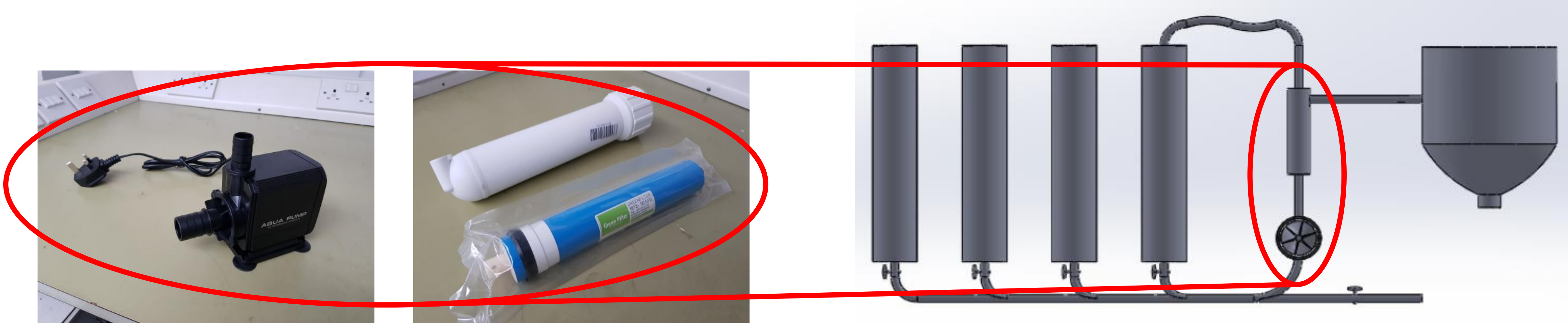






Closing Statements and Further Work

- The final stage is the extractor system but this is relatively easy to construct and will be done alongside the upscaling of the algae.

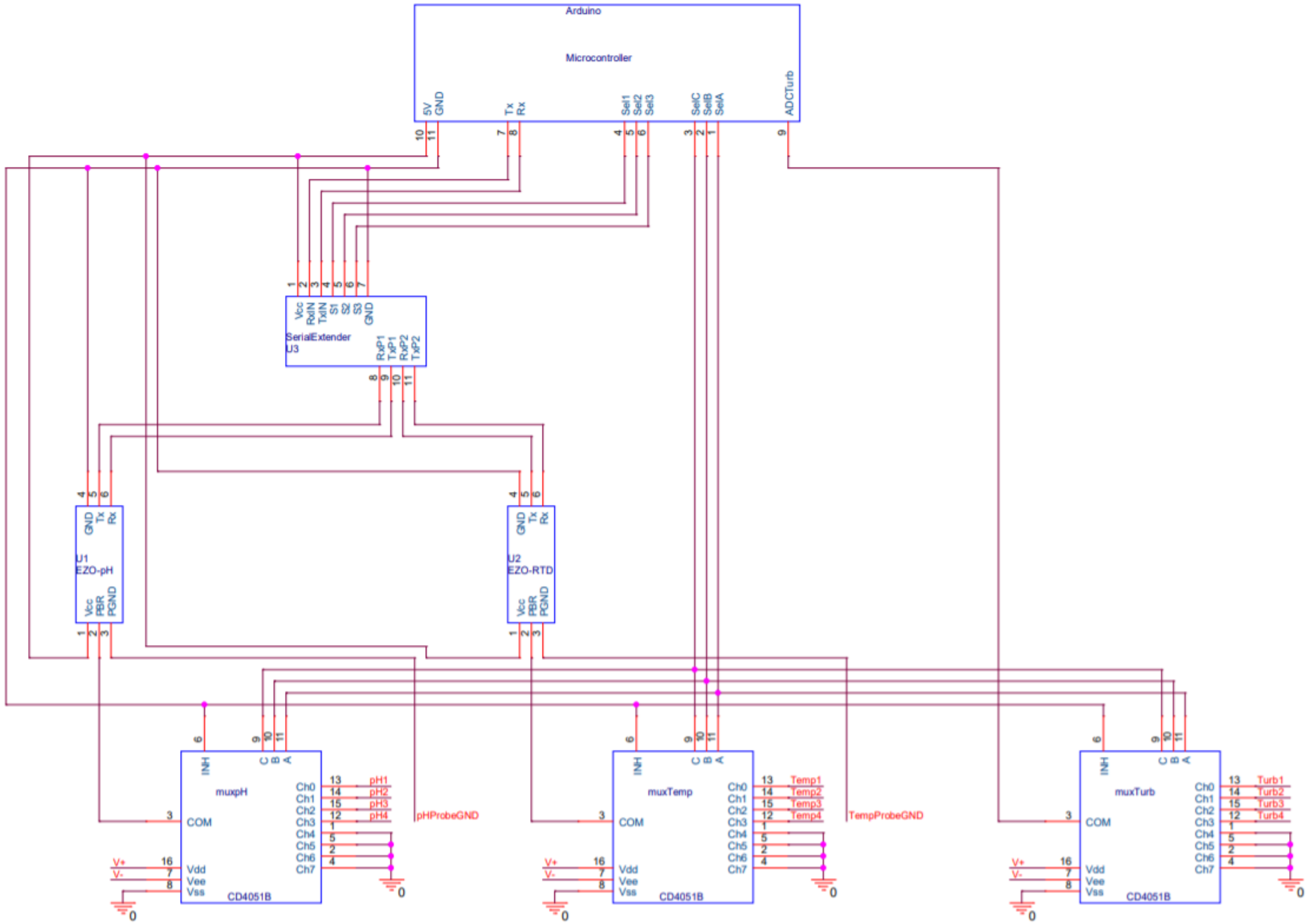


- This is based off of the system built by Michael Gerardo at Swansea University.

  https://www.youtube.com/watch?v=coBWiMc_iEI

Closing Statements and Further Work

- The sensor and actuator system should be completed and integrated into a working CO_2 delivery system this week for upscaled growth. The solenoid valve will be controlled by the pH readout via a mini controller.



Thank you for listening,

Do you have any questions?