Design and development of an automated continuous harvesting system for microalgae photobioreactors

Group 9: UFPR - FSU FIPSE Team
Presentation Date: October 20, 2015
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Ben Bazyler
Courtnie Garko

ENERGIA AUTOSSUSTENTÁVEL

NÚCLEO DE PESQUISA E DESENVOLVIMENTO

Team 9

Team memb… d roles.

1982 FLORIDA A&M UNIVERSITY FLORIDA STATE UNIVERSITY COLLEGE OF ENGINEERING

Kaelyn Badura - UFPR Team Lead

Yuri Lopes - FSU Team Lead

Ben Bazyler - Finance and Inventory Manager

Courtnie Garko - Scale and Process Engineer

Benalle Lemos - Hydraulics Specialist

Tomas Solano - Lead Mechanical Engineer

Project Overview

Currently, there are no viable or scalable methods for automated harvesting of the microalgae, leading to low efficiency production and low autonomy.

An automated and continuous harvesting process would lead to increased biomass production and would reduce production time.

Goal Statement:

Design of an automated and continuous harvesting system for microalgae.

Fig 1. Industry scale microalgae photobioreactor. at NPDEAS (UFPR), Curitiba, Brazil.

Key Technical Questions

- How to best standardize the FSU based cultivation?
- How to design a larger than laboratory scale enclosed cultivation system?
- What is the time required to harvest 1 gram of algal biomass per liter of culture?
- How to optimize design to keep space usage to a minimum?
- How to create a no loss system characterized by the reuse of recycled medium?

Project Objectives

- Biomass production process must be fully automated.
  - From cultivation, collection, flocculation, and separation.
- Must have ability to separate produced biomass and clarified water.
- Must work for batch sizes, semicontinuous, and continuous collection.
- Must incorporate continuous flocculation and sedimentation.
- Must minimize energy and resource consumption
- System must be scalable
- Will work with different species of algae.

Concept Design

Concept Generation and Selection

Design Breakdown

FSU Led Cultivation Initiative

1. Medium Component Design (preparation, input)
2. Cultivation Design
3. Sensor and Automation

UFPR Led Harvesting and Extraction Initiatives

1. Design of Flocculation Process Components
2. Separation and Extraction of Biomass
3. Sensor and Automation

Cultivation Initiative

Automated Cultivation Design Needs

1. Composition
   - Sensors to determine water and medium composition
   - Valves for volume input control
2. Mixing
   - Minimize moving parts
   - Use gravity as much as possible
3. Recycling
   - Section to recycle clarified water
   - Determine medium composition and add correct amount of recycled medium to keep composition constant
4. Cultivation
   - Air tube for mixing and supplying CO_2
   - Light fixtures to distribute light evenly

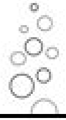
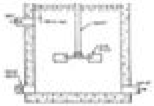
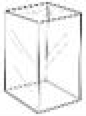
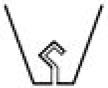
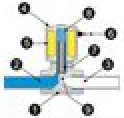
Option 2	Solutions		
Function			
Composition Sensors	Volume	Force	Displacement
Mixing			
Structural Design			
Transferring Fluid			

Fig 2. Morphological Chart showing selected design components for option 2, all selected components were the highest ranked.

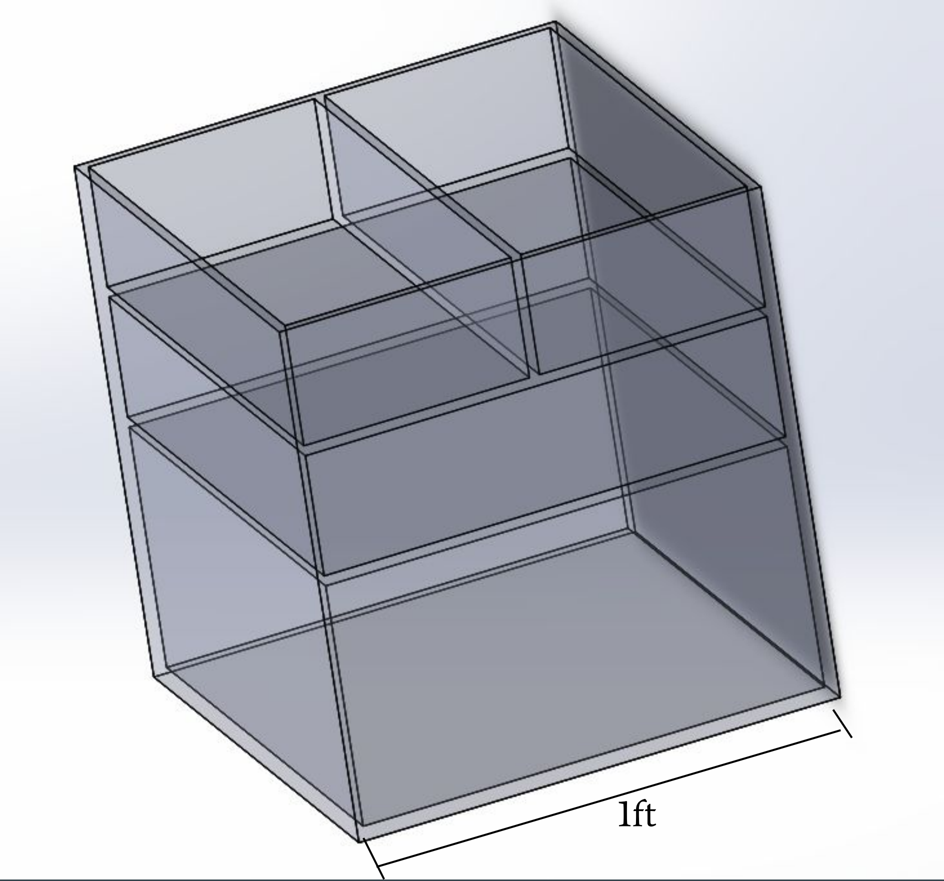


Fig 3. Cultivation Enclosure Design Concept CAD Drawing

Harvesting and Extraction Initiative

Automated Harvest Design Needs

1. Coagulation
   - Addition of flocculant to aggregate algae cells (glue)
   - Flash mixing to ensure homogenous composition
2. Flocculation
   - Low speed mixing algae cell conglomeration
3. Sedimentation and Clarification
   - Sedimentation caused by gravitational effects on the agglomerates
   - Larger surface area speeds up sedimentation
   - Flow control; avoid short circuit or break up of agglomerates
   - Clarified water exits over weir and sedimented algae (sludge) remains
4. Extraction
   - The sedimented algae sludge is a thick and viscous substance
5. Sensors and Automation
   - Light sensors and Arduino microcontroller

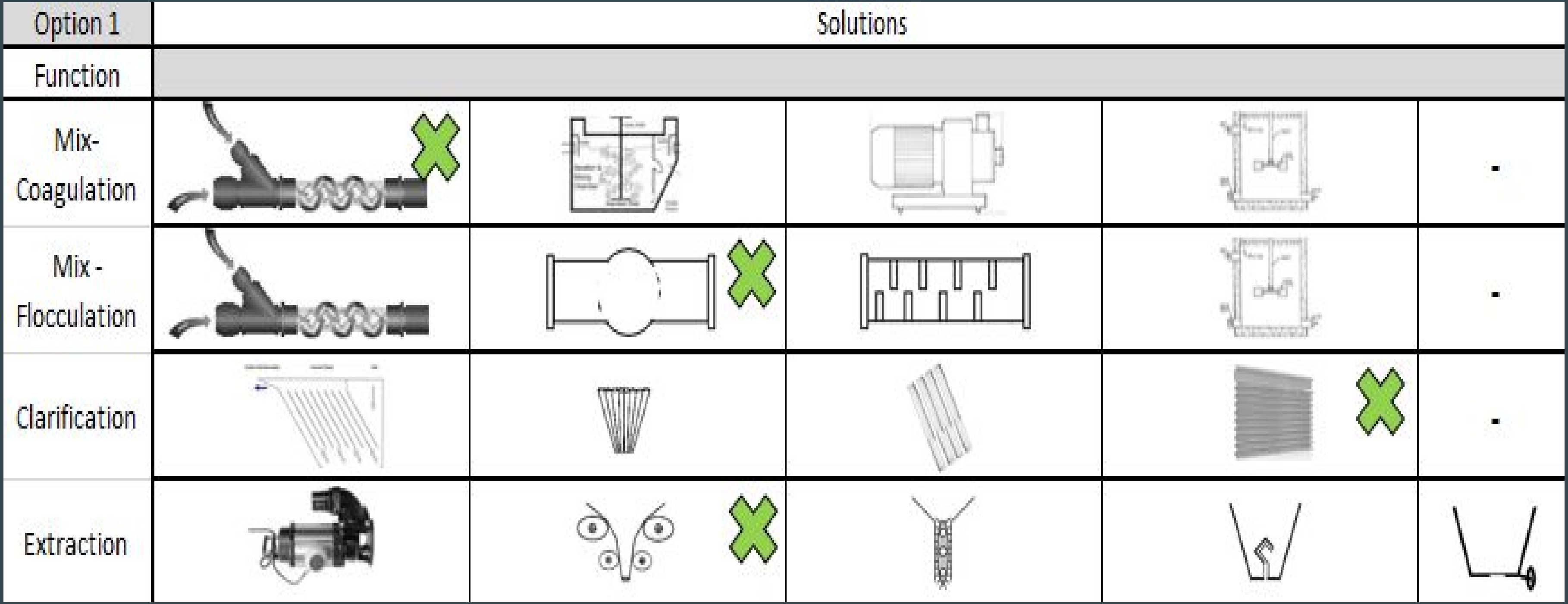


Fig 4. Morphological chart showing selected component designs for option 1, all selected components were the highest ranked.

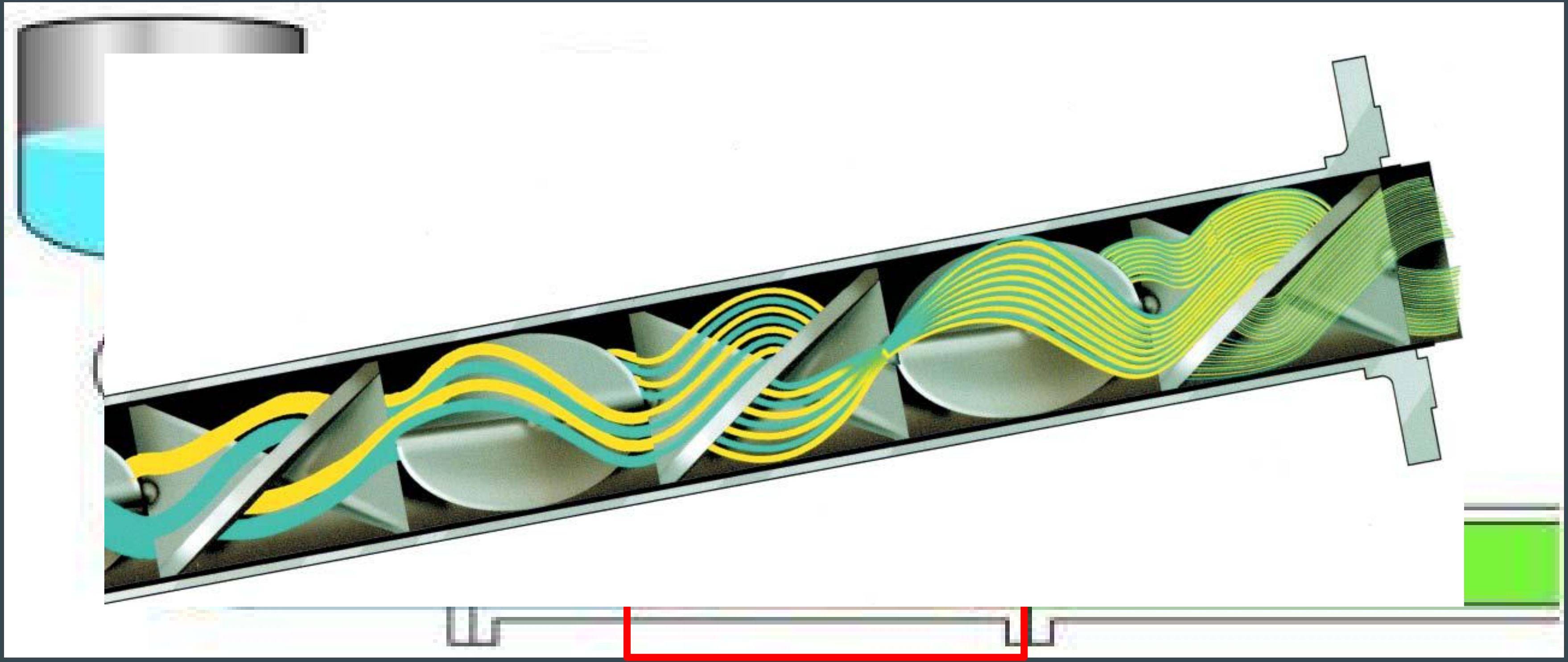
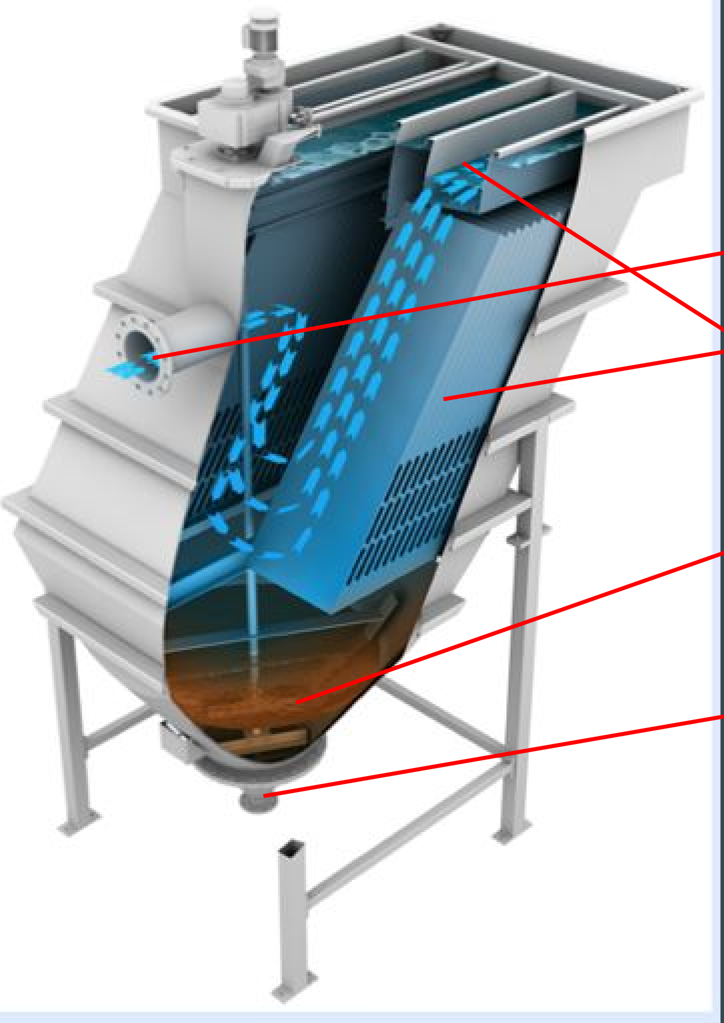


Fig 5. Inline mixer example



Inlet - after flocculation

Lamella - corrugated for increased surface area

Sludge Blanket

Weir - clarified medium overflow outlet

Extractor/dewaterer - modified peristaltic pump

Fig 6. Lamella Clarifier example

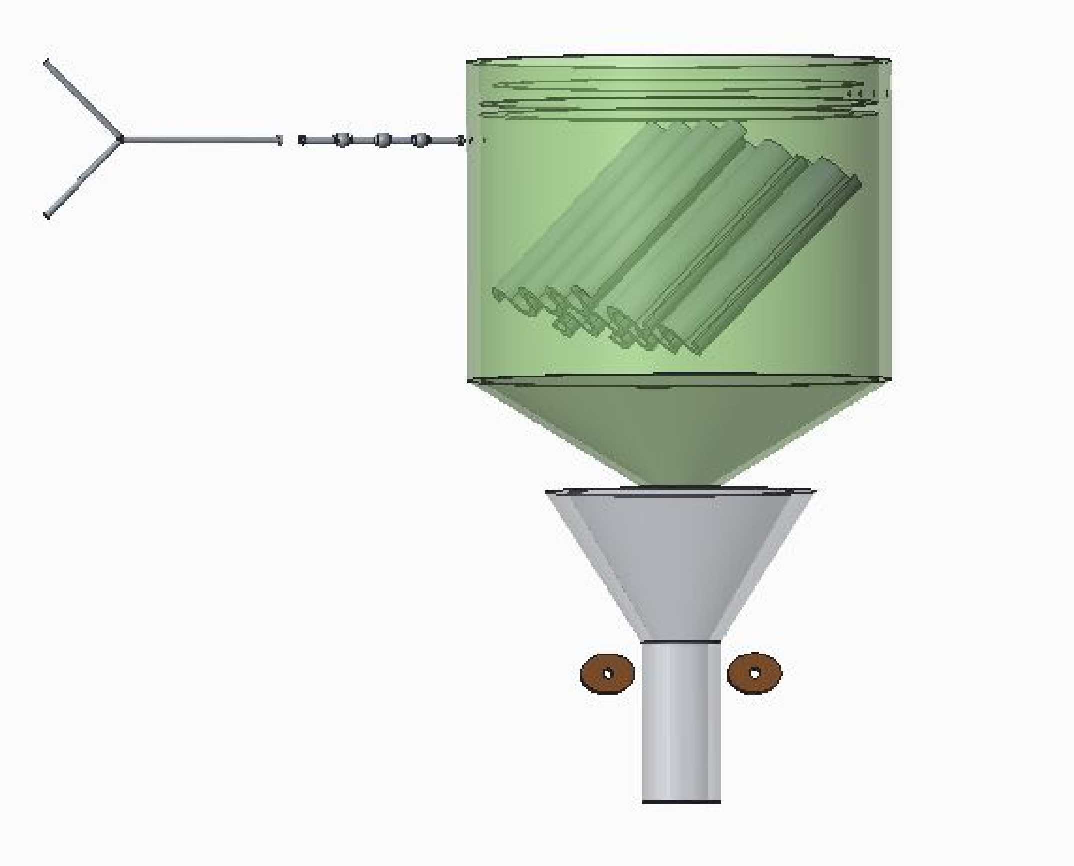


Fig 7. CAD Drawing of conceptual clarification and extraction system.

Automation

Cultivation:

- Density Sensor + LED/Transistor pair (refilling)
- Solenoid Valves (transporting)
- Arduino (microcontroller)

Harvesting and Extraction:

- 2 IR LED's and Phototransistors (magnitude of light)

Fig 8. Automation devices

Flocculation and Coagulation

- In line static mixers were chosen for the coagulation of the harvesting process.
  - Low cost, low maintenance, no energy
  - Achieve equivalent of rapid mixing for 30 seconds
- Mixing "bulbs" were chosen for flocculation.
  - Circular mixing to promote even agglomeration
  - Achieve equivalent of gentle, slow mixing for 20 min

Clarifier

- A tank in which sedimentation occurs
- Lamella structures chosen to increase sedimentation area and decrease retention time
- Baffles used to control flow

Extractor

- A modified peristaltic pump will be developed and implemented for the sludge extraction
- Pump will extract and dewater the sludge

Design Challenges and Risks

Cultivation

- Light and CO_2 distribution in larger scale systems
- Ensuring longevity of live algal cultures.

Harvesting

- Homogeneous mixing
- Design of a modified peristaltic pump to simultaneously extract and dewater the sludge

System

- Recycling of clarified medium.

Logistical Challenges

Current Challenges

- Algae growth (FSU campus)
- Finance Allocation
- Acquiring SuppliesGeographically Dispersed Team

Future/Potential Challenges

- Use of current photobioreactor
- Separate prototype construction

Future Plans

FSU

1. Finish designing and selecting the harvesting components
2. Allocate project budget and purchase supplies
3. Begin to cultivate algae
4. Begin small prototype build

UFPR

1. Dimensionalizing clarifier tank
2. Flocculation time tests
3. Lamella structures characterization
4. Flocculator and clarifier prototype build

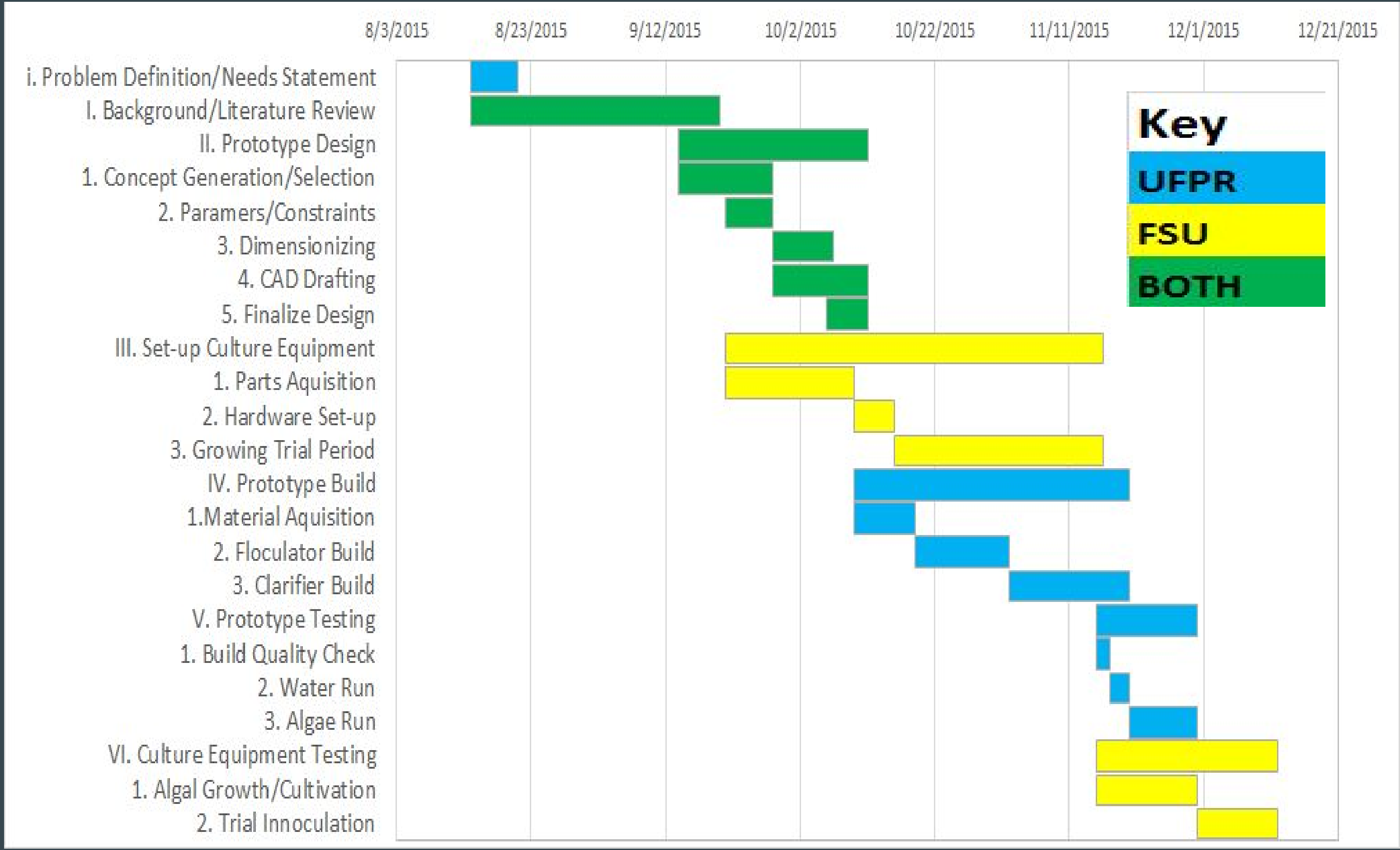


Fig 9. Team 9 Gantt chart for Fall 2015 semester.

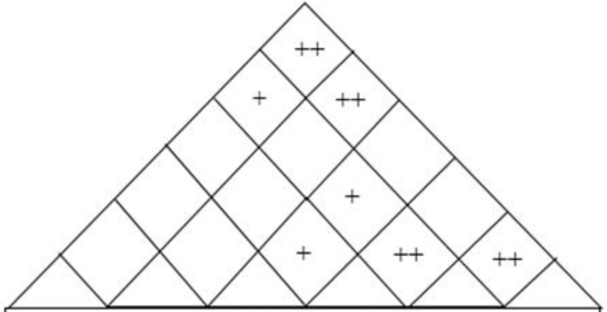
Summary

Component designs evaluated based on needs

- Cultivation: Optimize efficiency
  - Gravity + Air pump to minimize moving parts and power
  - Solenoid valve + displacement sensor for automation
- Harvesting: Increase production, decrease time and size
  - Static Mixer
  - Lamella clarifier
  - Peristaltic pump

Appendices

Appendix A: House of Quality



			Engineering Characteristics							
		Importance	Volume	Resistance to corrosion	Cost of Energy	Micro-Controller Timing	Biomass extraction efficiency	Design of Clarifier	Customer Total	Percentage
Customer Requirements	Fully automated	5			1	9		3	65	22.90%
	Separate biomass	5	1			3	9	1	70	24.60%
	Works with different cycles	3	3			1			12	4.20%
	Continuous Flocculation + Sedimentation	5				9			45	15.80%
	Sustainable	3		9	9				54	19.00%
	Scalable	2	3					9	24	8.50%
	Works with different algae	2	1				3	3	14	4.90%
		Total	22	27	32	108	51	44		
		Percentage	7.70%	9.50%	11.30%	38.00%	18.00%	15.50%		

Fig A-1. House of Quality

Appendix B:
Medium Preparation and Cultivation Concept Generation

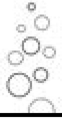
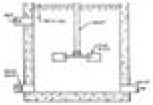
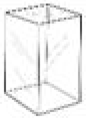
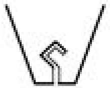
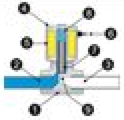
Option	Solutions		
Function			
Composition Sensors	Volume	Force	Displacement
Mixing			
Structural Design			
Transferring Fluid			

Fig B-1. General morphological chart showing all generated component designs

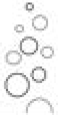
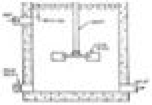
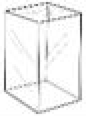
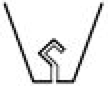
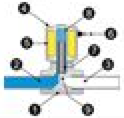
Option 1	Solutions		
Function			
Composition Sensors	Volume	Force	Displacement
Mixing			
Structural Design			
Transferring Fluid			

Fig B-2. Morphological chart showing all selected components for option 1

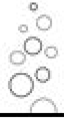
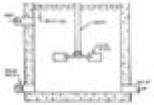
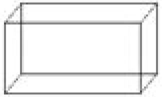
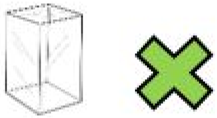
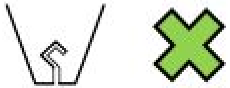
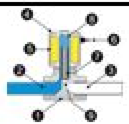
Option 3	Solutions		
Function			
Composition Sensors	Volume 	Force	Displacement
Mixing			
Structural Design			
Transferring Fluid			

Fig B-3. Morphological chart showing selected components for option 3, a third possibility

Function: Composition Sensors	Criteria					
Solutions (Weight)	**Cost (2)**	**Size (1)**	**Power (2)**	**Effectiveness (3)**	**Implementation (2)**	**Total**
1. Mass flow rate sensor	1	8	9	8	7	33
Volume	2	8	18	24	14	**66**
2. Force sensor (mat)	5	5	8	6	4	28
Force	10	5	16	18	8	**57**
3. Displacement sensor	10	9	9	6	8	42
Displacement	20	9	18	18	16	**81**

Fig B-4. Decision matrix for composition sensors

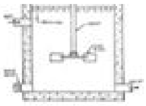
Function: Mixing (Medium)	Criteria					
Solutions (Weight)	Cost (2)	Size (1)	Power (2)	Maintanence (2)	Implementation (3)	Total
1. Static Inline Mixer	3	5	10	10	6	34
	6	5	20	20	18	**69**
Air pump	9	7	6	8	8	38
	18	7	12	16	24	**77**
Mechanical Mixer	2	4	4	3	4	17
	4	4	8	6	12	**34**

Fig B-5. Decision matrix for a mixing mechanism

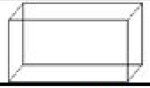
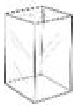
Function: Structural Design	Criteria					
Solutions (Weight)	**Cost (2)**	**Size (2)**	**Effectiveness (1)**	**Maintanence (2)**	**Implementation (3)**	**Total**
1. Erlenmeyer Flasks	2	6	5	8	5	26
	4	12	5	16	15	**52**
2. Horizontal Tank	6	7	5	4	5	27
	12	14	5	8	15	**54**
3. Vertical Tank	6	8	9	4	5	32
	12	16	9	8	15	**60**

Fig B-6. Decision matrix for structural design

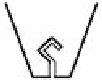
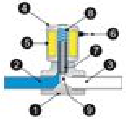
Function: Transferring Fluid	Criteria					
Solutions (Weight)	Cost (2)	Size (2)	Power (2)	Maintanence (1)	Implementation (3)	Total
1. Pump	3	3	2	4	7	19
	6	6	4	4	21	**41**
2. Auto Syphon	9	8	10	8	3	38
	18	16	20	8	9	**71**
3. Solenoid Valve	7	9	8	7	7	38
	14	18	16	7	21	**76**

Fig B-7. Decision matrix for a fluid transfer mechanism

Appendix C:
Harvesting and Extraction Initiative Concept Generation

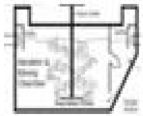
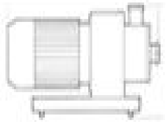
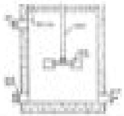
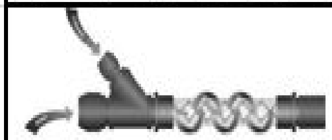
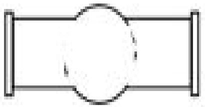
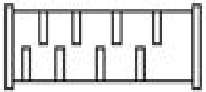
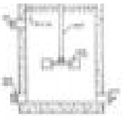
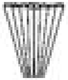
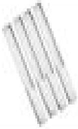
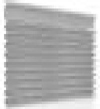
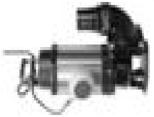
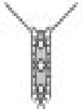
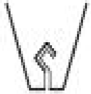
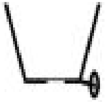
Option	Solutions				
Function					
Mix-Coagulation					-
Mix - Flocculation					-
Clarification					-
Extraction					

Fig C-1. General morphological chart showing all generated component designs

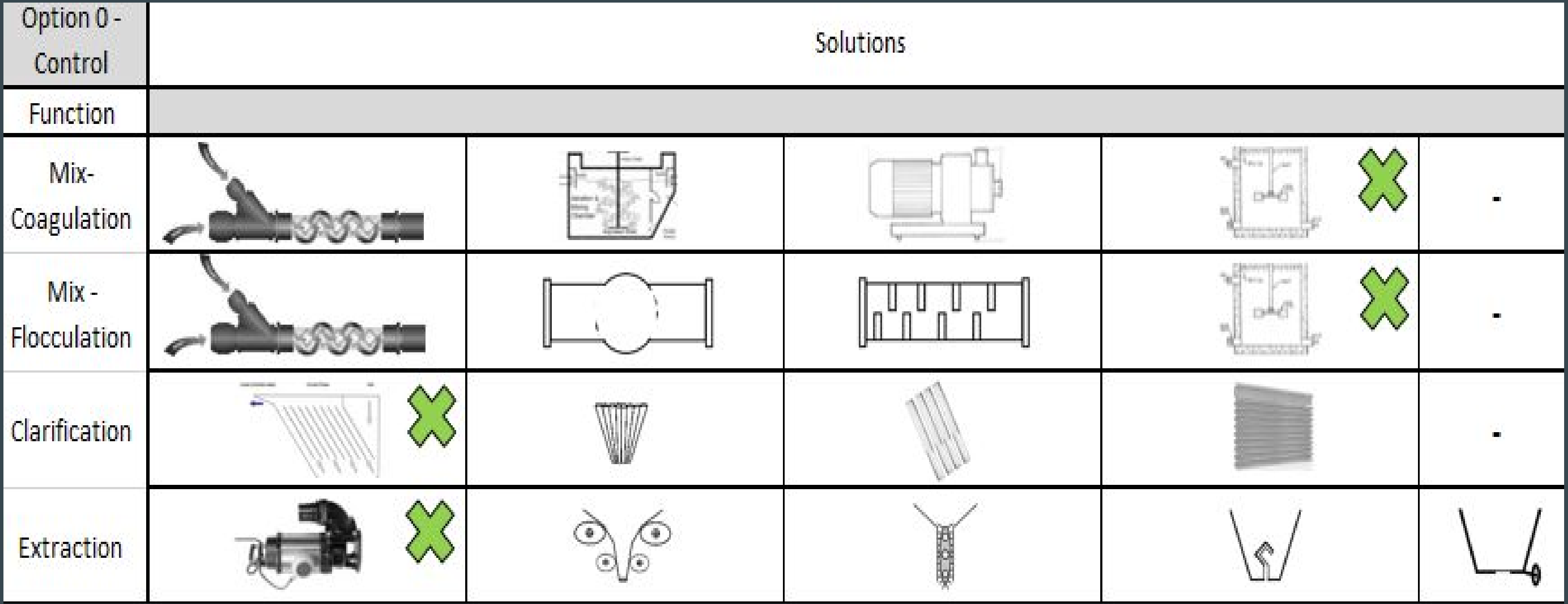


Fig C-2. Morphological chart showing all selected component designs for the control (standard) design

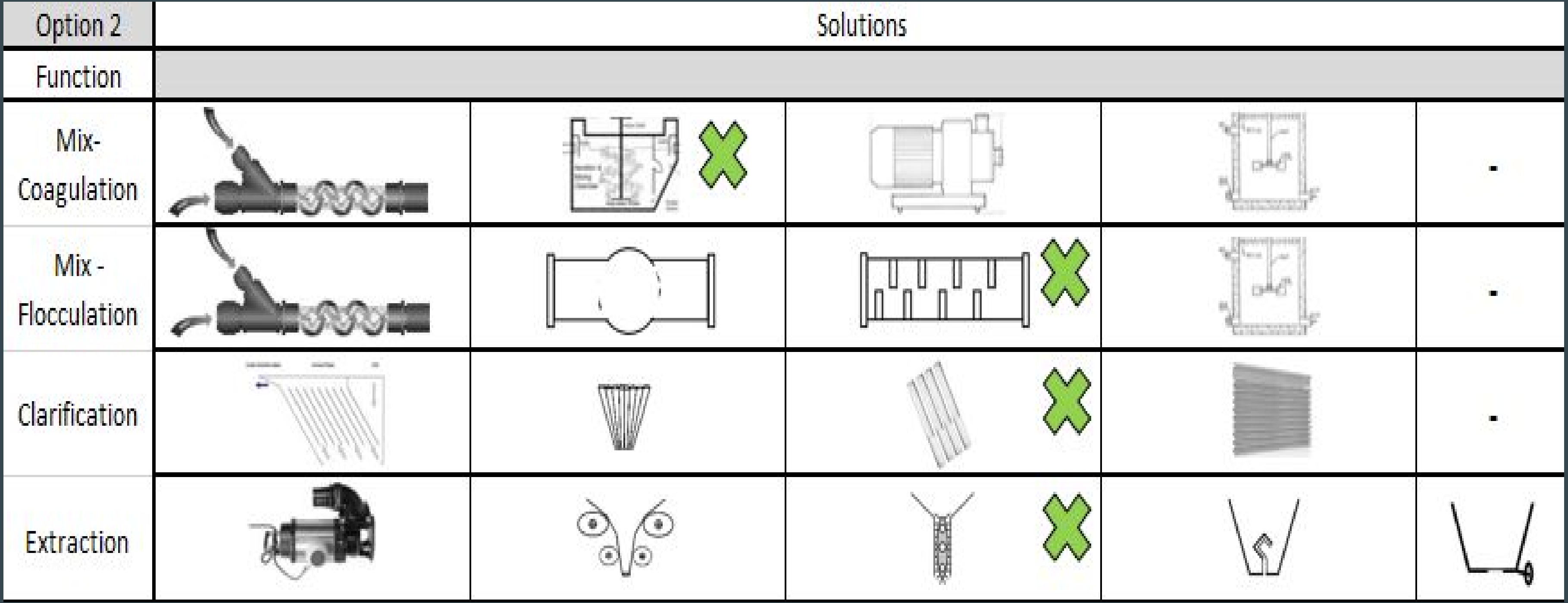


Fig C-3. Morphological chart showing selected component designs for option 2, all components were second highest rated

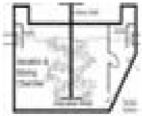
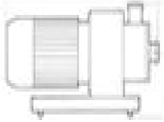
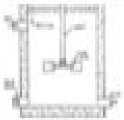
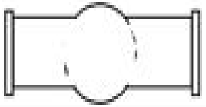
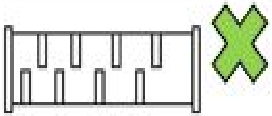
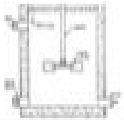
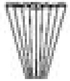
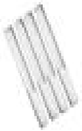
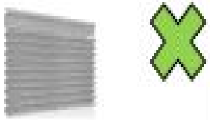
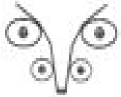
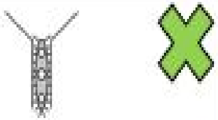
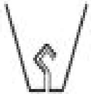
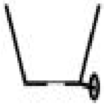
Option 3	Solutions				
Function					
Mix-Coagulation					-
Mix - Flocculation					-
Clarification					-
Extraction					

Fig C-4. Morphological chart showing selected component designs for option 3, created from a mixture of option 1 and 2 components

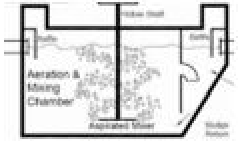
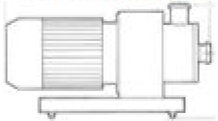
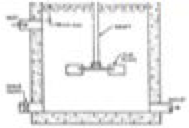
Function: Mixing (Coagulation)	Criteria					
Solutions (Weight)	Cost (2)	Size (1)	Power (2)	Maintanence (2)	Viability (3)	Total
1. Static Inline Mixer	8	9	10	7	6	40
	16	9	20	14	18	**77**
2. Aeration	9	5	6	5	7	32
	18	5	12	10	21	**66**
3. Inline Kinetic Mixer	2	7	4	3	5	21
	4	7	8	6	15	**40**
4. Kinetic Mix Tank	5	5	2	5	9	26
	10	5	4	10	27	**56**

Fig C-5. Decision matrix for component which fulfills function of coagulation- mixing

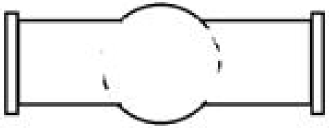
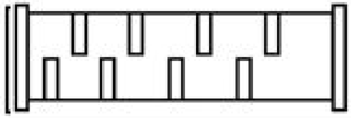
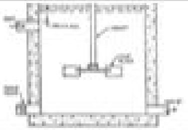
Function: Mixing (Flocculation)	Criteria					
Solutions (Weight)	Cost (2)	Size (1)	Power (2)	Maintanence (2)	Viability (3)	Total
1. Static Inline Mixer	8	9	10	7	6	40
	16	9	20	14	18	77
2. Mixing Bulb	9	8	10	8	8	43
	18	8	20	16	24	86
3. Baffles	10	9	10	6	8	43
	20	9	20	12	24	85
4. Kinetic Mix Tank	5	5	2	5	9	26
	10	5	4	10	27	56

Fig C-6. Decision matrix for component which fulfills function of flocculation- mixing

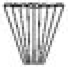
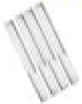
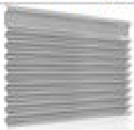
Function: Clarification	Criteria					
Solutions (Weight)	SA (3)	Cost (1)	Implementation (2)	Effectiveness (3)	Novel (1)	Total
1. Parallel Lamella Plates	6	10	10	5	1	32
	18	10	20	15	1	64
2. Conical Arrangement Lamella Tubs	5	7	4	7	7	30
	15	7	8	21	7	58
3. Parallel Angled Lamella Tubes	9	8	8	8	5	38
	27	8	16	24	5	80
4. Parallel Angled Corrugated Lamella Plates	10	7	8	10	7	42
	30	7	16	30	7	90

Fig C-7. Decision matrix for component which fulfills function of clarification

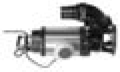
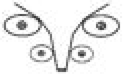
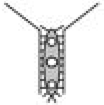
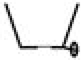
Function: Biomass Extraction	Criteria						
Solutions (Weight)	Cost (2)	Power (1)	Novel (2)	Viability (1)	Maintanence (2)	Effectiveness (2)	Total
1. Pump	1	5	1	10	6	10	33
	2	5	2	10	12	20	51
2. Cam Swallow Mechanism	4	6	8	6	4	7	35
	8	6	16	6	8	14	58
3. Conveyor/Scrubber	5	6	5	7	4	8	35
	10	6	10	7	8	16	57
4. Autosiphon	7	8	5	7	5	2	34
	14	8	10	7	10	4	53
4.Free Fall Value	8	8	1	8	8	2	35
	16	8	2	8	16	4	54

Fig C-8. Decision matrix for component which fulfills function of extraction

	Baseline	Alternative Solutions		
Criteria	Current Solution	Option 1	Option 2	Option 3
Cost	4	2	1	1
Sustainability	1	1	0	0
Adaptability	3	0	-1	0
Maintanence	2	1	-1	0
Effectiveness	5	1	0	1
∑ Positives	-	16	4	9
∑ Negatives	-	0	-5	0
Total	-	16	-1	9

Fig C-9. Pugh matrix for design configuration evaluation

Appendix D:
Harvesting and Extraction Initiative CAD Concept Drawings

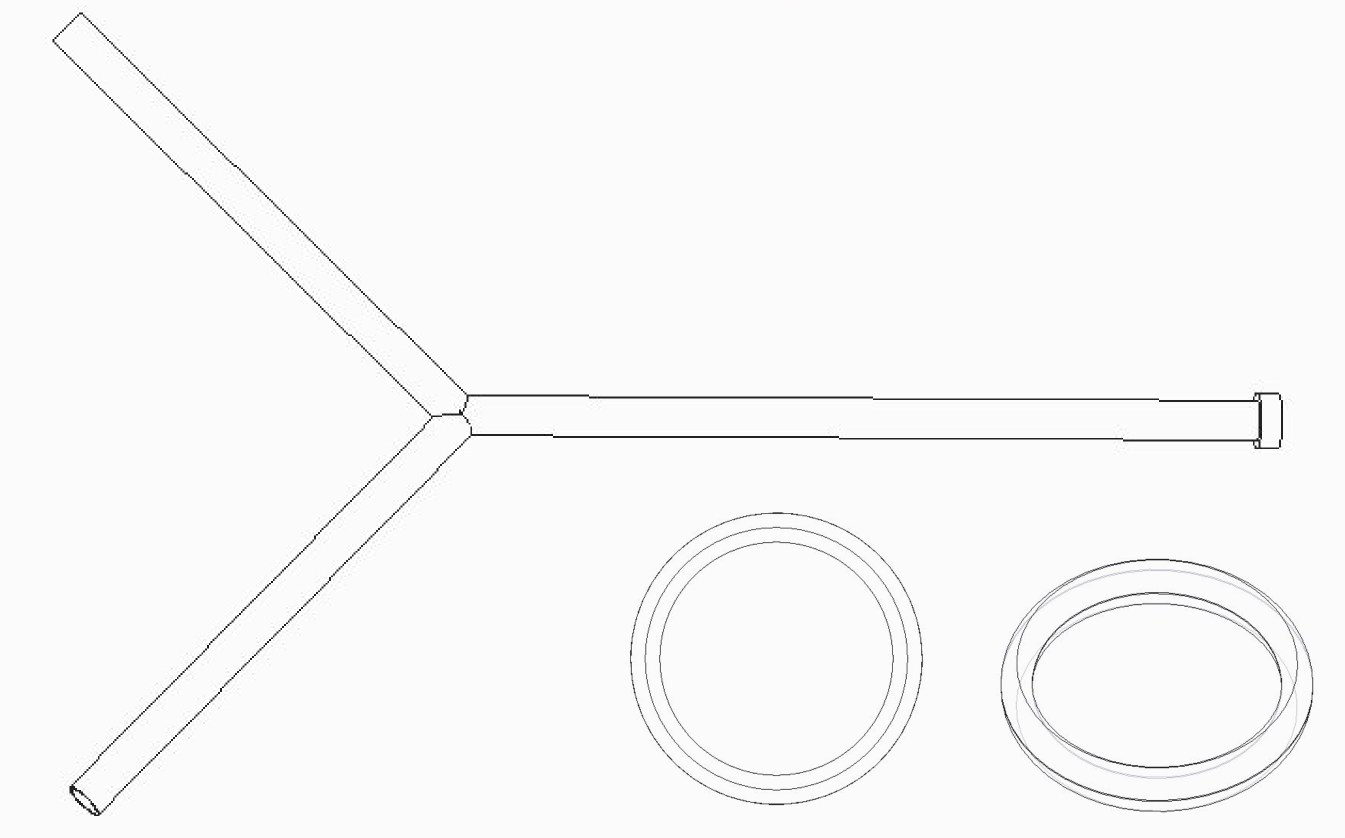


Fig D-1. CAD Drawing for 3 junction static inline mixer and seal used to prevent leaks in piping connections.

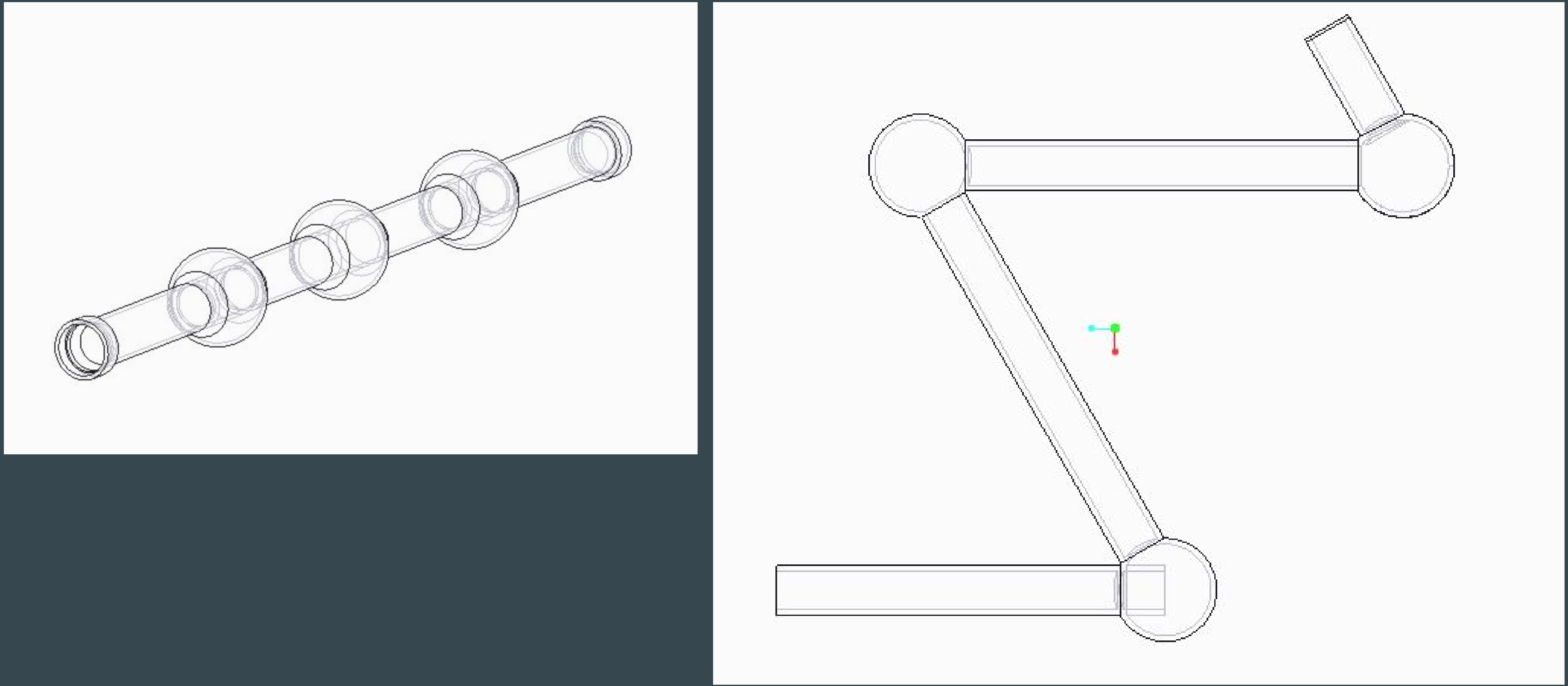
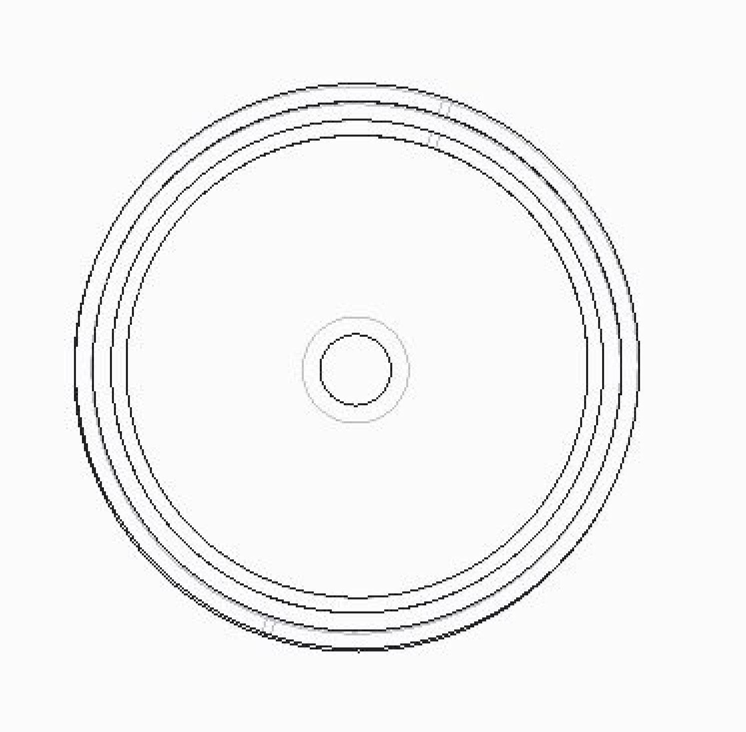


Fig D-2. CAD concept drawings of bulb mixing mechanism.



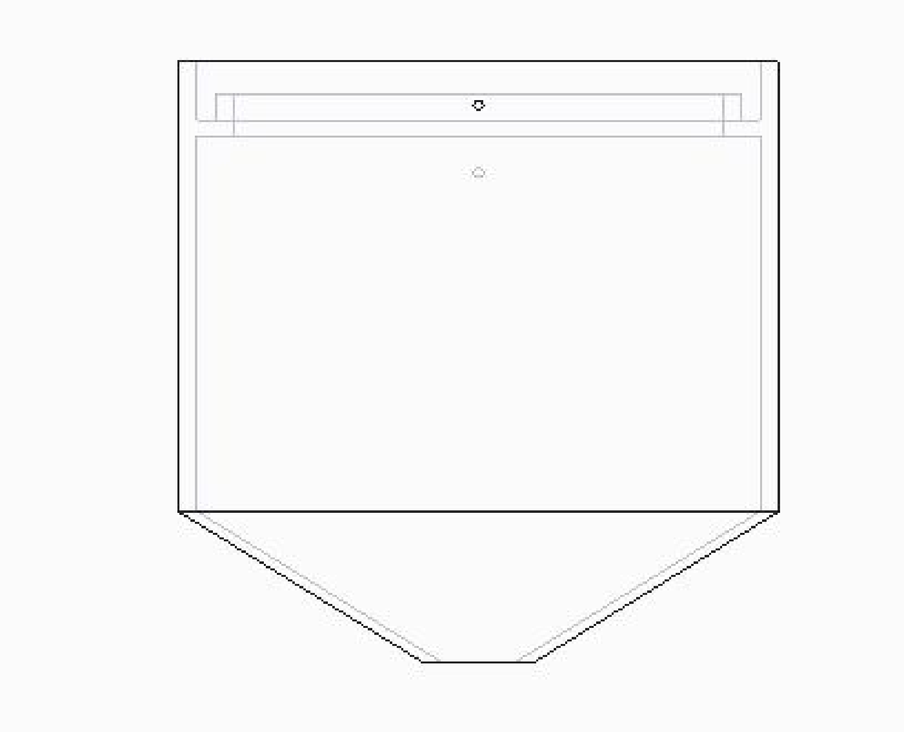


Fig D-3a,b. a. (Left) Top CAD drawing view of conceptual sedimentation tank, b. (Right) Profile view of sedimentation tank.

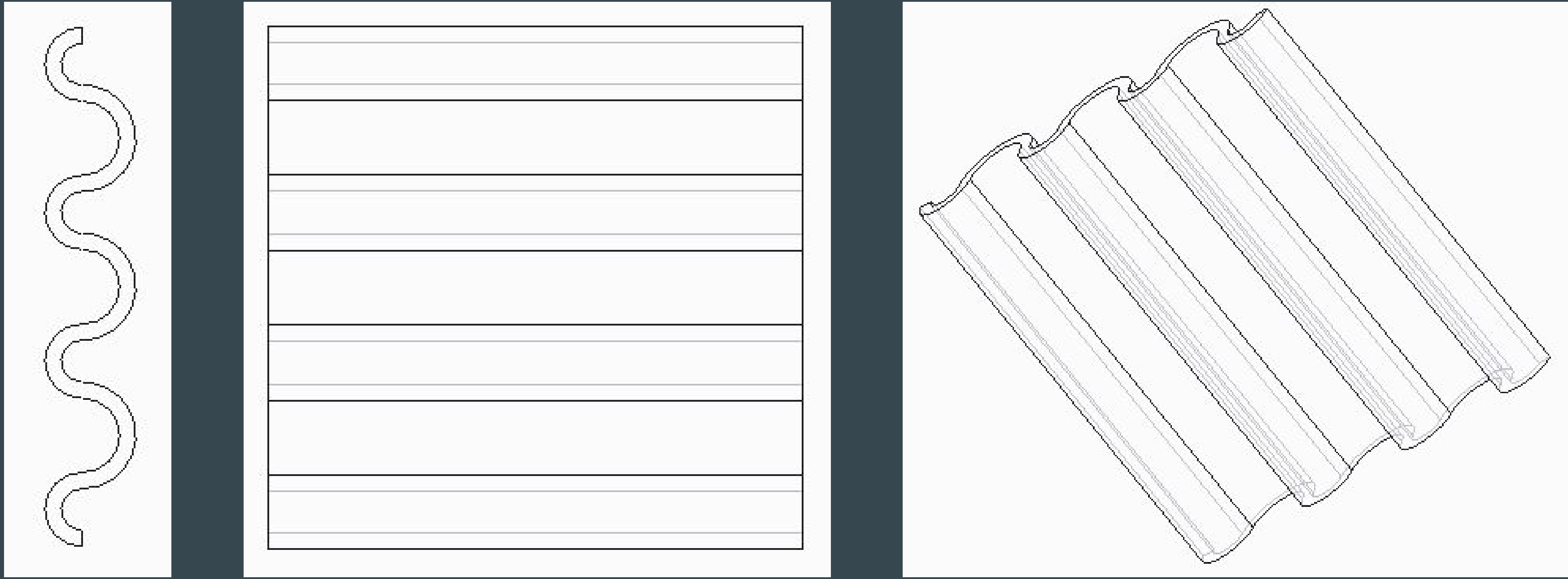


Fig D-4a,b,c. a) (Left) Profile view of conceptualized corrugated lamella, b) (Center) Front view of lamella, c) (Right) Default view of lamella.

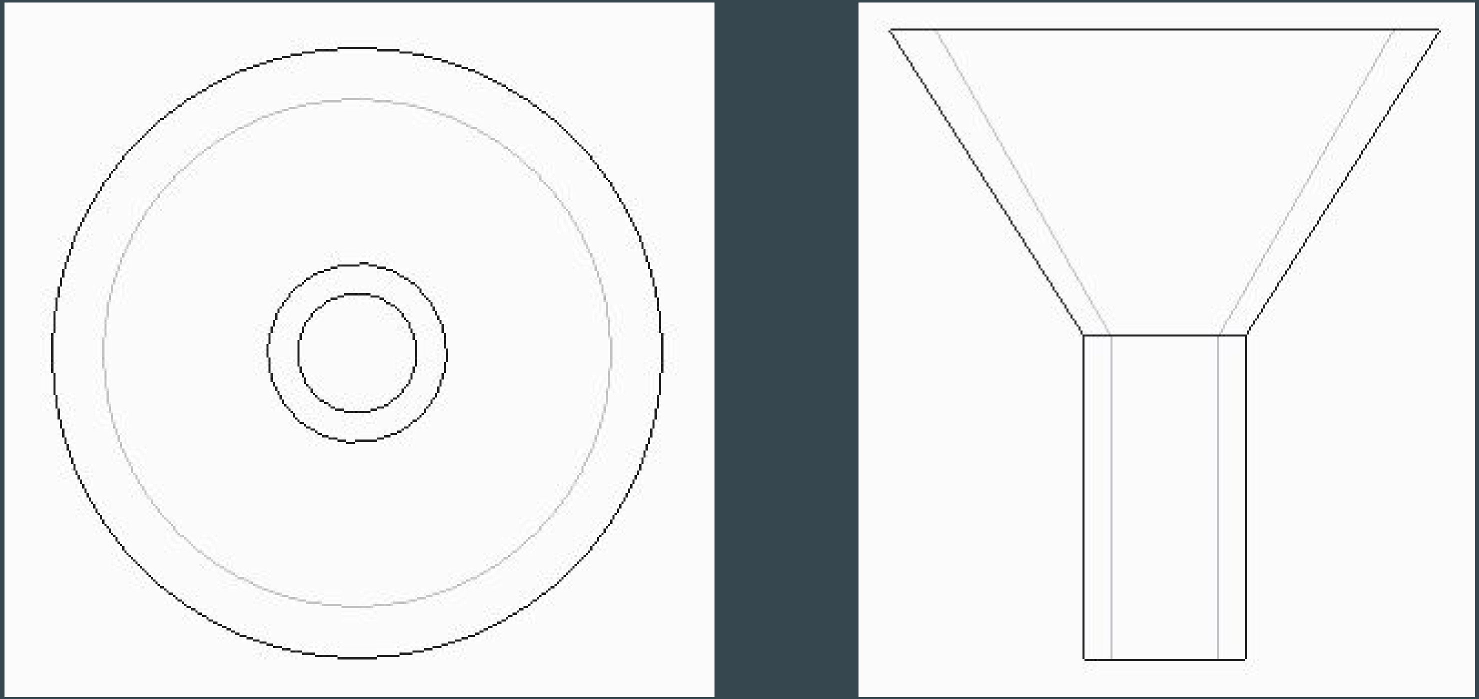


Fig D-5a,b. a. (Left) Top view of flexible extractor funnel, b. (Right) Profile view of funnel.

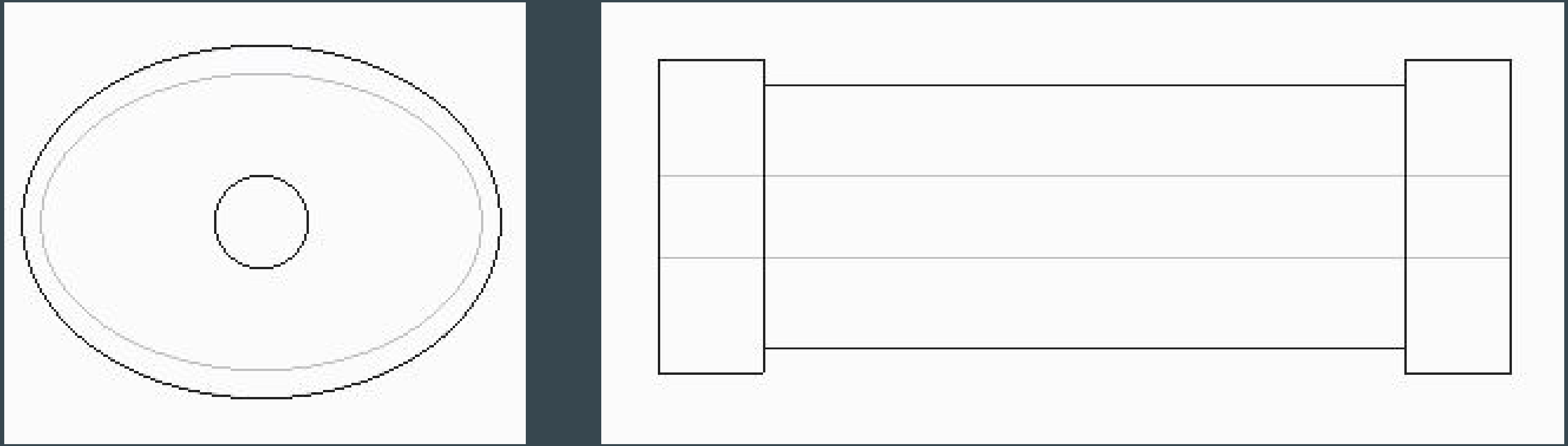


Fig 6 a,b. a) (Left) Profile View of concept cam to be used with extractor funnel, b) (Right) Longitudinal view of cam.