Restated Project Definition, Scope, and Plan

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

Team Number: Group 9, FIPSE: UFPR - FSU Senior Design
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I. Problem Statement

As a result of waning fossil fuel resources it is desirable to have access to a sustainable alternative energy source. Microalgae photobioreactors are viable options for simple and sustainable energy source production. The operation of these bioreactors has the potential for automation and produces environmentally friendly biomass and biogas which have many widespread applications, as aforementioned. The current state of microalgae photobioreactors is very dependent on consistent maintenance and check-ups to keep the algae growing. In addition, there are no viable methods for automated harvesting of the microalgae. This is unsatisfactory because it limits biomass yield and the scope of microalgae as a large scale biofuel source. UFPR in conjunction with FSU are sponsoring the Senior Design team to develop a continuous harvesting system which requires minimal intervention as a solution to the harvesting problem.

II. Project Scope

The overall project scope for the automation of a continuous harvesting system for microalgae remains the same for the 2016 spring semester as it did in the Fall 2015 semester. Key technical considerations, goal statement, objectives, and constraints can be seen restated below.

1. Key Technical Considerations

This is a fundamentally interdisciplinary project which fuses heavily weighted mechanical engineering concepts including control volume flow and flow control with chemical engineering, and life sciences.

There are many pressing ideas, concepts, and processes which need to be considered during the development and execution of this design project. There are five main technical considerations which will direct the evolution of this project.

These five key technical considerations include:

- Standardization of cultivation process and procedure.
- The design of a larger than laboratory scale enclosed cultivation system which effectively demonstrates scalability of laboratory scale proof of concept.
- Investigation and optimization of time required to harvest 1 gram of algal biomass per liter of culture.
- Optimization of space efficiency of developed design to keep space usage to a minimum
- Creation of a minimal to no loss system characterized by the reuse of recycled medium.

2. Goal Statement

The goal statement specified within a project outlines the general aims of the project. For Group 9, the FIPSE: FSU – UFPR Senior design team, the goal statement is given below.

Goal Statement: “Design of an automated and continuous harvesting system for microalgae

3. Project Objectives

Objectives are tangible milestones against which to gauge progress and quantify success in fulfilling the outlined goal. The relevant objectives for the design of an automated and continuous harvesting system for microalgae are defined below.

- Biomass production process must be fully automated.
    - From cultivation through collection and flocculation to separation.
- System must have ability to separate produced biomass and clarified water.
- Must work for batch, semicontinuous, and continuous collection.
- Must incorporate continuous flocculation and sedimentation.
- Must be sustainable, both in construction and in process.
    - Minimized energy and resource consumption.
- System must be scalable and will show functionality at both lab and pilot scales.
- Harvesting system will work with different species of algae.

4. Project Constraints

These are requirements potential designs must meet in order to be fully considered as a legitimate and appropriate design which meets sponsor’s expectations. There are eight main logistical and technical constraints outlined for the design and development of an automated and continuous harvesting system for microalgae photobioreactors.

- The developed system must work with FSU’s current skeleton photobioreactor infrastructure.
- The total cost may not exceed $1,500.
- The clarified medium must be recyclable.
- The produced biomass must remain usable (aimed towards the production of biodiesel) and should require no additional purification.
- Harvesting process should be continuous, with the option of batch or semi-continuous operation, and requires minimal human interaction.
- Entire laboratory scale system must be less than 10 m^2 and should accommodate at most, 10 L in cultivation and sedimentation chambers.
- The entire system’s flow rate will be dictated by the growth rate of the utilized microalgae. The growth rate of each algae is different and therefore the system must be able to adapt.
- Developed system must function in various environments and be able to maintain a cultivation temperature of 16-27 °C.

III. Product Specifications

Design Specifications:

At the moment, the only limiting engineering feature of this design is the size of the system. For this project, our goal is to have two fully functioning systems of varying size. The first system will be designed for collegiate purposes and will be restrained to the size of an average table so that universities can use the device in a simple lab setting and will be constructed using a mini-airlift system. The second device will be created for quasi-industrial purposes and will make use of a mini-photobioreactor.

The purpose of creating these two devices is to validate the scalability of the device and to see if any drastic changes need to be made depending on the size of the system. For example, one limiting agent when dealing with a larger scale for photo bioreactors is the amount of light that can reach the algae based on the diameter of each tube and the distance between each tube whereas with smaller systems, lighting may not be an issue however issues may arise with very small scale flow control and automation.

Currently there are no pressing concerns with other constraints such as stress, load and weight as no constraints were given in the problem statement or specified by the sponsor. In the design and construction process, these aspects will still be considered in order to be good stewards of resources and to create an effective and efficient design. The purpose of this project is to simply make the continuous system operational at various sizes and to minimize the necessary human-system interaction. In some way, power can be considered an indirect constraint due to the fact that the energy production potential of the harvested biomass should, ideally, be greater than the power consumed in the process of producing and harvesting the biomass to yield an acceptable process efficiency.

Performance Specifications:

The primary performance specification of this project is that the final system be a fully functioning, continuous, autonomous photobioreactor that produces usable microalgae biomass. This process will consist of maintaining a constant living microalgae supply which is harvesting at an appropriate collection point (cellular density is acceptable for separation), separating the microalgae from the medium, extracting the algal biomass and recycling the medium. A secondary specification is that the process be scalable and have demonstrable proof of concept for two scale function such that it operates at a lab and a pilot scale. The sponsor did not specify particular performance specifications outside of the realm of autonomous and continuous operation of the system.

IV. Project Plan

1. Methods

The design of an automated microalgae cultivation and harvesting system consists of three major interrelated components: the control for the automation of the system, the cultivation system, and the biomass separation system. It is important to note that the control for the automation of the system is composed of the microcontroller, source code, and actuators and that the harvesting system includes the development, automation, and implementation of the pulsed electric field (PEF) lysing chamber.

In order to provide a comprehensive view of the project plan and the methods performed to complete the project the progress made in the fall semester will first be outlined, followed by an explanation of the objectives and plans for the Spring 2016 senior design semester. A more concrete schedule can be seen in section 2, entitled "Project Schedule".

Fall 2015 in Review

The Fall 2015 semester began with an extensive literature review which consisted of reading and compiling an ample library of relevant research meant to aid in the design of a microalgae biomass production and harvesting system. Following this, a comprehensive conceptual design was generated using the morphological method. The finalized design included a partitioned culture preparation stage, an algal cultivation stage, PEF lysis for biomass separation, recycling of the leftover medium and a peristaltic pump to remove the biomass. Due to the nature of the project during the fall semester the design group, as well as the equipment was geographically disbursed. Technical testing was performed by the students stationed at UFPR under the available technical expertise with the appropriate equipment. This testing included flocculant efficiency testing and PEF lysis circuit and chamber design. Additionally, the circuit and chamber were constructed and a basic mathematical model was constructed to help simulate the production and separation of the microalgae biomass. The students stationed at FSU designed and constructed the infrastructure for the algal growth which would be need in the Spring 2016 semester. The FSU group was also able to successfully grow the first batch of *Scenedesmus Obliquus* microalgae.

Spring 2016 Plan

For the Spring 2016 semester, Team 9 will continue to focus on the three main components of control, cultivation, and separation. This will be accomplished primarily through the automation of the entire biomass production process from cultivation through harvesting. Inherent in this objective is the need for new algal cultivation, the development of the pulsed electric field (PEF) lysing, laboratory scale prototyping using an airlift photobioreactor, and pilot scale prototyping using a mini-photobioreactor.

For the entire duration of the Spring semester algae will be cultivated using this infrastructure build last semester so that it is readily available for pulsed electric field lysis testing and inoculation. This infrastructure consists of a series of Erlenmeyer flasks, lights, stoppers which contains the medium and algae as well as tubing and a pump which aerate the cultures.

A large objective is the completion of the PEF lysis mechanism which includes the circuitry and the lysis chamber. The construction of both of these items was slated for completion by the end of January, however the first prototype of each has already been built. This semester the main focus with the PEF lysing is to amplify the output voltage and to perform a proof of concept to verify that the setup does indeed cause cellular lysis and that this lysis will be sufficient to separate the microalgae biomass from the medium. Following this validation, the mechanism will be modified, optimized, and the timing chip will be replaced by a microcontroller to allow more intelligent control of the system lysis. Final testing and calibration will be performed after the implementation of the timing chip. This system will then be ready for prototype installation.

This semester the prototyping of the design will occur using two different setups within two staggered time frames. Initially, Team 9 will focus on making sure all team members are familiar with FSU's skeleton mini-airlift and skeleton photobioreactor. The mini-airlift is currently missing components and requires further design work. The photobioreactor does not function as its pump is not strong enough to overcome the pressure losses resulting from minor losses and the height differential. These missing components will be designed and implemented in order to prepare the airlift for use and a new pump will be selected and purchased for the photobioreactor. During this period the airlift and the photobioreactor will be cleaned and otherwise prepared for utilization. Following the installation of the new parts and pump, both units will undergo a wet run, where water is run through the system, in order to check for sealing problems such as leaks. The automation process for the table top airlift will then commence focusing on the automation of medium preparation/input and flow control to modulate the collection, lysis, and separation of the produced biomass. After the automation has been finalized for the tabletop unit, the process will be scaled and implemented for the pilot scale photobioreactor. Once automation is functioning and finalized for both the tabletop airlift and the pilot photobioreactor, both units will be inoculated and monitored. Testing, remaining calibration, and any final adjustments will then be made in order to optimize the system performance to the best of team 9's ability.

2. Project Schedule

For the Spring 2016 semester, Team 9 will focus primarily on the automation of the entire biomass production process from cultivation through harvesting. This includes new algal cultivation, the development of the pulsed electric field (PEF) lysing, laboratory scale prototyping using an airlift photobioreactor, and pilot scale prototyping using a mini-photobioreactor. Algal cultivation will continue for the entire duration of the spring semester and the PEF lysing has been allotted 33 days for development and automation concluding by February 8, 2016. The prototyping of the microalgae biomass production systems has been allotted the greatest portion

of time, a duration of 85 days. Automation of both systems needs to be accomplished by the end of February in order to allow ample for system inoculation and optimization. Prototyping initiatives will concluded by March 31, 2016 in order to allow preparation time for final presentations. A tabular format of Team 9's Spring 2016 schedule can be viewed in figure 1. Additionally, a Gantt chart for the Spring 2016 semester can be found as figures 2 and 3 in the appendix of this paper.

Task	Start	Duration	End
Problem Defintion Through Concept Design	**8/3**	***150***	**1/1**
Spring Algae Cultivation	**1/11**	***100***	**4/20**
Order/Receive New Algal Culture	1/11	*9*	1/20
Grow Algae Batches	1/20	*91*	4/20
Development of PEF Lysing	**1/6**	***33***	**2/8**
Build PEF Lysing Circuit/ Chamber	1/6	*16*	1/22
Proof of Concept and Effectiveness	1/22	*3*	1/25
Modification/Optimization	1/26	*5*	1/31
Automation	1/26	*5*	1/31
Testing and Final Adjustments	1/31	*8*	2/8
Table Top Unit: Mini-Airlift	**1/6**	***85***	**3/31**
Familiarize with FSU Skeleton Design	1/6	*5*	1/11
Design Missing Components	1/12	*6*	1/18
Purchase/ Install Components	1/19	*8*	1/27
Clean/ Pepare for use	1/28	*2*	1/30
Wet Run and Leak Check	2/1	*2*	2/3
Automation and Testing	2/5	*21*	2/26
Innoculation	3/1	*13*	3/14
Testing and Final Adjustments	3/14	*17*	3/31
Scaled Unit: PBR	**1/6**	***85***	**3/31**
Familiarize with FSU Skeleton Design	1/6	*5*	1/11
Clean/ Pepare for use	1/12	*8*	1/20
Wet Run and Leak Check	1/21	*2*	1/23
Automation and Testing	2/10	*16*	2/26
Innoculation	3/1	*13*	3/14
Testing and Final Adjustments	3/14	*17*	3/31

Fig 1. Team 9's Spring 2016 design project schedule.

3. Assignment of Resources

Fall 2015 Resource Allocation

- UFPR students - Tomas Solano, Kaelyn Badura
  - Conceptual design of separation and harvesting system
  - Method of medium recycling
  - CAD for respective portion of design
  - Familiarization of microcontroller automation of algae collection
- FSU students - Yuri Lopes, Courtnie Garko, Benjamin Bazyler
  - Design of medium preparation system

  - Design and construction of algae batch cultivation, algae growth
  - Connections between cultivation and harvesting systems
  - Initial sensor selection and design

Spring 2015 Resource Allocation

This semester there are a varied selection of initiatives needing to be completed including scheduling and logistics, unit maintenance and quality control, sensor design, control and automation, PEF lysis, calibration and testing, and website design. All team members are responsible for participating in unit maintenance as well as process control and automation as both are fundamental to successful completion of this project.

- Kaelyn Badura, Yuri Lopes - UFPR, FSU Team Co-Leads
  - Scheduling and logistics such as task delegation
  - Unit maintenance and quality control management
  - Project management, involvement in all design related activities
- Benjamin Bazyler - Finance and Inventory Manager
  - Inventory and finance management
  - Sensor development and calibration
  - System control and automation
- Courtnie Garko - Scale and Process Engineer
  - Website design
  - Specialized biomass/medium separation techniques
  - Process transition from lab to pilot scale units
- Benalle Lemos - Hydraulics Specialist
  - UFPR student point of contact
  - Flow control and optimization
- Tomas Solano - Lead Mechanical Engineer
  - PEF lysis circuitry
  - Sensor development and construction
  - Design calibration and testing

V. Current Project Status

All three of the main components of this system, including the control for the automation of the system, the cultivation system, and the biomass separation system, are in differing stages of development and implementation. The the completion of the tabletop airlift is slated for the month of January pending design finalization. Airlift parts will be ordered next week. Recently, an attempt was made to clean the mini photobioreactor and revealed several leaks and an ineffective pump. A new pump is currently being selected in order to improve circulation and will be installed next week. The available automation, sensors, actuators are being calibrated and synchronized through the microcontroller and additional sensors and sensor construction materials are in the process of being purchased. The prototype for the electric lysing, built at UFPR in Brazil during the fall semester 2015, is being optimized to initiate proof of concept testing. Additional algae has been ordered and algal growth will recommence when the algae cultures arrive.

VI. Appendix - Gantt Chart

		Spring Algae Cultivation	**73 days**	**Mon 1/11/16**	**Wed 4/20/16**
		Order/ Receive New Algal Culture	8 days	Mon 1/11/16	Wed 1/20/16
		Grow New Algae Batches	66 days	Wed 1/20/16	Wed 4/20/16
		Development of PEF Lysing	**24 days**	**Wed 1/6/16**	**Mon 2/8/16**
		Build PEF Lysing Circuit/ Chamber	13 days	Wed 1/6/16	Fri 1/22/16
		Proof of Concept and Effectiveness	2 days	Fri 1/22/16	Mon 1/25/16
		Modification/Optimization	5 days	Tue 1/26/16	Sun 1/31/16
		Automation	5 days	Tue 1/26/16	Sun 1/31/16
		Testing and Final Adjustments	7 days	Sun 1/31/16	Mon 2/8/16
		Table Top Unit: Mini-Airlift	**62 days**	**Wed 1/6/16**	**Thu 3/31/16**
✓		Familiarize with FSU Skeleton Design	4 days	Wed 1/6/16	Mon 1/11/16
		Design Missing Components	5 days	Tue 1/12/16	Mon 1/18/16
		Purchase/ Install Components	7 days	Tue 1/19/16	Wed 1/27/16
		Clean/ Pepare for use	3 days	Thu 1/28/16	Sat 1/30/16
		Wet Run and Leak Check	3 days	Mon 2/1/16	Wed 2/3/16
		Automation and Testing	16 days	Fri 2/5/16	Fri 2/26/16
		Innoculation	10 days	Tue 3/1/16	Mon 3/14/16
		Testing and Final Adjustments	14 days	Mon 3/14/16	Thu 3/31/16
		Scaled Unit: PBR	**62 days**	**Wed 1/6/16**	**Thu 3/31/16**
✓		Familiarize with FSU Skeleton Design	4 days	Wed 1/6/16	Mon 1/11/16
		Clean/ Pepare for use	7 days	Tue 1/12/16	Wed 1/20/16
		Wet Run and Leak Check	3 days	Thu 1/21/16	Sat 1/23/16
		Automation and Testing	13 days	Wed 2/10/16	Fri 2/26/16
		Innoculation	10 days	Tue 3/1/16	Mon 3/14/16
		Testing and Final Adjustments	14 days	Mon 3/14/16	Thu 3/31/16

Figure 2. Tabular portion of spring 2016 Gantt chart. Start/end days are same as in scheduling, duration differs slightly as it only accounts for weekdays.

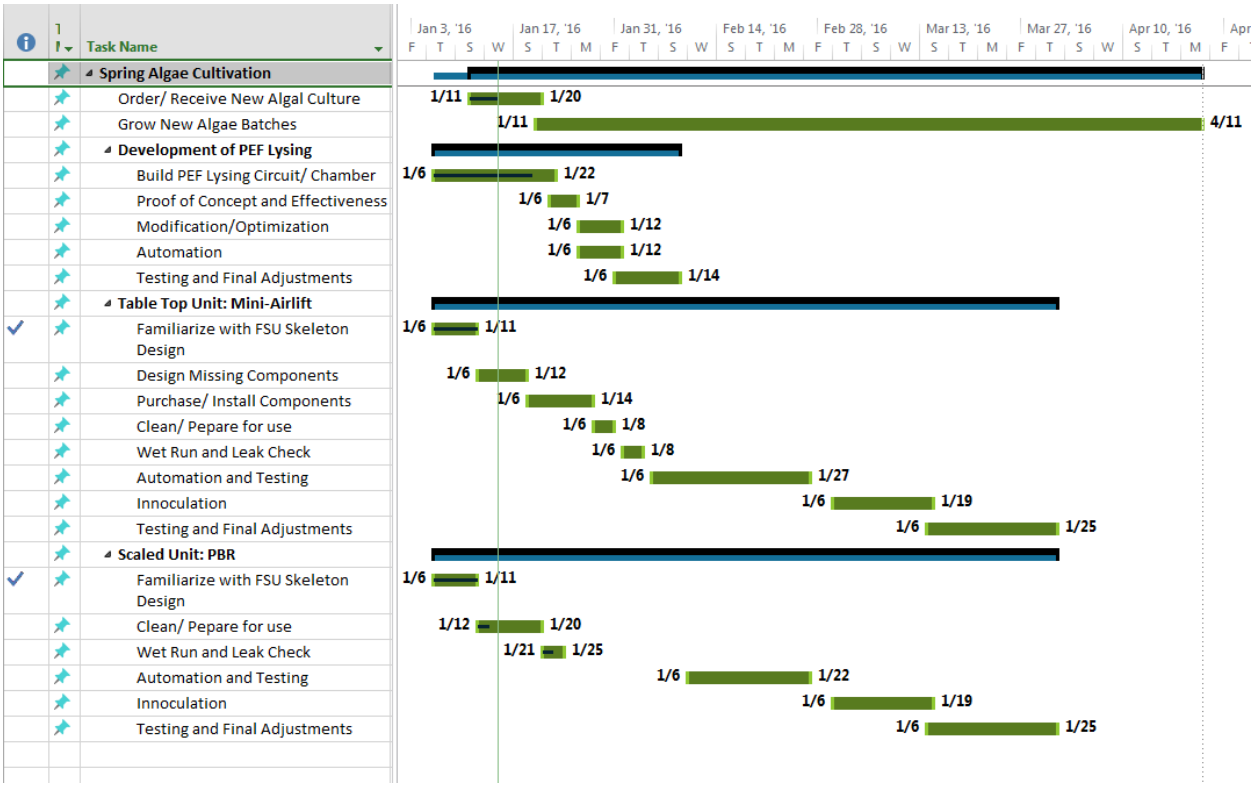

Figure 3. Spring 2016 Gantt chart. Start/end days are same as in scheduling, duration differs slightly as it only accounts for weekdays.