Project Plan and Specifications

Senior Design Project (EML 4551C) - Fall 2013 Deliverable
Team 07 - Microalgae Photobioreactor

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1.0 Problem Statement

The customer defined the problem statement in the project proposal as:

> "The UFPR-FSU senior design teams have worked in the past with photobioreactors that work in batches. Growth media is added initially to microalgae to be grown in the photobioreactor for a period of approximately 15 days. At the end of that period the biomass is extracted and a new batch starts.
>
> We anticipate enhance biomass productivity by using a continuous growth system (as opposed to batch) in which biomass is continuously extracted as new cells grow attempting to maintain a nearly constant ideal cell concentration within the photobioreactor. Media (nutrients and water) will need to be added in the necessary amounts to make up for the extractions.
>
> The implementation of a continuous system, requires at least: (i) a concentration sensor, (ii) an automatic unit of media supply, and (iii) a biomass extraction unit. The concentration sensor was partially developed by the 2012-2013 team (see link under background), and it will be further enhanced as part of a master thesis. What you are asked to design is the units (ii) and (iii), and amend the previously developed concentration sensor (i)."

Thus, the customer needs a way to transform the photobioreactors' current "batch" growth systems into "continuous growth systems." In order to achieve this, the customer is requesting the design or development of an "automatic unit of media supply" and a "biomass extraction unit", as well as an improvement to the "previously developed concentration sensor."

2.0 Background and Justification

Coal, petroleum, and natural gas are all nonrenewable resources commonly used today. As consumption continues to increase, these resources are becoming more and more unsustainable. If changes are not made or alternatives are not found, these resources will eventually run out, crippling infrastructures and industries on a global scale. In addition, greenhouse gasses will continue to increase and negatively affect the environment. New methods of energy production and consumption must be implemented before significant consequences occur. Alternative fuels, such as biofuels derived from oils in crops, present one solution to this energy problem. Some examples of biofuel crops are corn, soybean, sugar cane, canola, and microalgae. Microalgae are the only biofuel that can completely replace our existing fuel sources. Microalgae take little room to grow compared to crop biofuels and produce biomass much quicker than other crops. According to Yusuf Chisti, within twenty-four hours, microalgae can double its biomass (*Biodiesel from Microalgae*).

The Florida Agricultural and Mechanical University – Florida State University College of Engineering (FAMU-FSU COE) in Tallahassee, FL, USA and the Federal University of Paraná (UFPR) in Curitiba, Paraná, Brazil started a partnership on senior design projects in 2005. The projects are unique in that they require international collaboration between universities. In this section, brief reviews of the past projects are explained. We will focus on the projects from 2010-present because the 2010 group was the first team to implement the microalgae in their objectives. The designs and prototypes mentioned below are currently at the FAMU-FSU COE. These were created based on existing photobioreactor systems and research at UFPR.

Starting in 2010, the combined team, consisting of a group at UFPR and a group at FAMU-FSU COE, developed a new way to monitor the effects of carbon dioxide on microalgae. The FAMU-FSU COE team built a bench-top airlift photobioreactor. The CO_2 was supplied though the bottom of the airlift tubes, rose through the algae, and exited out the top. The microalgae concentration was monitored by counting the cells under a microscope and the optimal amount of CO_2 to get the most cell growth was determined (*Senior Design Proposal*).

Figure 1 shows the Trigenerator System with Photobioreactor. This was completed by the 2011 Senior Design team. (Senior Design Project)

In 2011, the team implemented this knowledge of the effect of CO_2 on microalgae into a trigeneration system. The trigeneration system was built by the 2005 senior design team. It is a system that created hot water, electricity, and refrigeration from fuel in an internal combustion engine. The final project is shown in fig. 1 (*Senior Design Proposal*).

The 2012 team went in a different direction. They built a mini-photobioreactor at the FAMU-FSU COE, designed as a small-scale prototype of the one in Brazil. In addition, they designed and implemented concentration and mass flow rate sensors to determine the optimal time to extract the microalgae in order to obtain the most biomass before it starts to die. The use of these sensors, when calibrated correctly, can save significant time compared to the previous method of manually counting microalgae cells. The mini-photobioreactor built in 2012 is shown in fig. 2 (*Senior Design Proposal*).

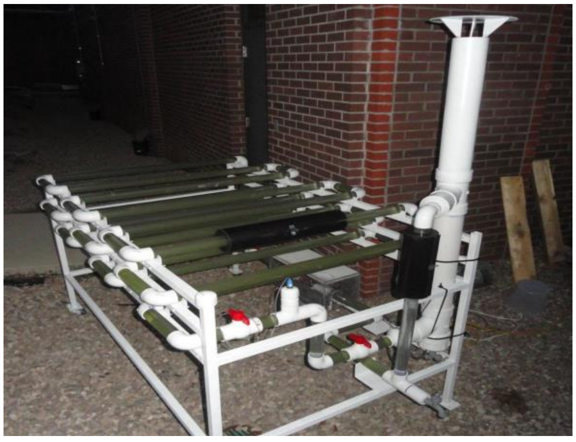


Figure 2 shows the Photobioreactor created last year. It incorporated sensors to monitor the microalgae growth. (Senior Design Project)

This year's project will include several objectives that build on the efforts of previous groups and a few objectives that require the design of new devices, as well. The project is intended to reach a milestone of continuous photobioreactor operation, as well as to build more resources for research at UFPR and FAMU-FSU COE to strengthen this collaborative international project.

3.0 Objectives

The main goal of this project is to satisfactorily complete, as defined by the customer, objectives 1-4 listed below and complete objective 5 only if the previous objectives have been completed. The deadline for this goal is the end of spring semester 2014. The FAMU-FSU College of Engineering and Federal University of Paraná will work together to accomplish these tasks. The objectives were either obtained from the project proposal submitted by the customer or through dialogue with the customer about the project.

The main objectives for the FALL/SPRING SEMESTERS are as follows:

1. *Grow two types of microalgae*
2. *"Design and develop two devices (units) for low cost, automatic growth media addition and biomass extraction from photobioreactors."* (*Senior Design Proposal*)
3. *"Submission of an invention disclosure in the US and a patent in Brazil of a concentration / mass flow rate sensor."* (*Senior Design Proposal*)
4. *Improve previously developed mass flow rate and concentration sensors*
5. *"Design and develop a platform (12 L airlift photobioreactor) to test such automatic units."* (*Senior Design Proposal*)

4.0 Methodology

Planning and organization will be essential to a successful international project. The FAMU-FSU College of Engineering and Federal University of Paraná teams will have to work together to achieve the objectives listed above. The overall project will be divided into two teams: the FAMU-FSU team and the UFPR team. The FAMU-FSU team consists of three mechanical engineers and a chemist. The engineering team will consist of a project leader, sensor and mechatronic team leader, and algae team leader. The chemist will work with the algae team leader to create and maintain the proper chemical compositions of the algae and food. The UFPR team consists of one FSU student and four UFPR students. At least once a week, the two teams will meet by video conference to provide updates and address relevant problems. All major design processes such as brainstorming or concept generation, as well as important group decisions will be discussed via video conference.

The first task of the FAMU-FSU team will be to grow two different types of algae. After the algae are grown, the team will make any necessary modifications to the mass flow rate and concentration sensors to improve their functionality – i.e. their modularity, mobility, and ease of use. While working on the above tasks, an invention disclosure will be filed with Florida State University. This is a disclosure that tells the University this technology may be worth patenting. The goal is to have the sensors calibrated and improved by the end of the fall semester. If this goal is accomplished, a 12L airlift Photobioreactor will be built in the spring. Dr. Ordonez is the advisor and sponsor of the FAMU-FSU team.

In Brazil, the UFPR team will first complete a patent application to Instituto Nacional da Propriedade Industrial (INPI) in Brazil for the mass flow rate and concentration sensors. The goal is to complete the patent application within the first month of the project. Next, they will be developing the algae extraction and media addition units. These units must be adaptable to all existing photobioreactor systems at FAMU-FSU COE and UFPR. The goal is to have a working prototype by the end of the fall semester in order to be tested during the spring semester. Dr. Vargas is the advisor and sponsor of the UFPR team.

5.0 Expected Results

Customer identified expected results as outlined by Ordonez and Vargas in the project proposal:

1. *"Design and construct operational units."*
2. *"Design and construct an airlift photobioreactor to test the sensors."*
3. *"Provide enough experimental data to test operation of the designed units."*
4. "It should be fully *automated."*
5. *"It should be low-cost."*
6. *"It should be for long term outdoor use."*
7. *"Units must be scalable and readily adaptable to: 12L airlift photobioreactor (to be constructed by the team), existing mini-photobioreactors (at FSU and UFPR)."*
8. *"Write an invention disclosure (FSU team) to be submitted to the USPTO by the OTT/FSU and a patent request (Brazilian team) to be submitted to the Brazilian INPI, for the concentration/mass flow rate sensor developed by the 2012/2013 team."*
9. *"Estimated Costs of Hardware, or Items Provided by Sponsor: Approx. $3000"*

Additional expected results:

1. *Have a healthy culture of microalgae maintained for testing*.

The expected result of the entire project is to have all of the components required for continuous algae-growth both developed and tested. Currently, on the full-scale photobioreactor in Brazil, algae concentration is still determined from manual counting and the entire system operates on "batch" system marked by operational stops for algae extraction, media addition, and system cleaning. By the end of the academic year, the team expects all photobioreactor at FAMU-FSU COE and at UFPR to be capable of operating continuously – where algae are extracted and media added without needing to shut down the system. The team expects significant time savings and an increase in overall rate of biomass extraction.

6.0 Constraints

The time it takes for the algae to grow is a major constraint of this project. Before any of the sensors can be calibrated, a sufficient amount of algae must be grown. This process can take up to two month and must be started right away to not have any delays. Another constraint will be communication. In an international project, it will be vital to keep communication so progress continues according to expected deadlines. Weekly video conferences will be made to keep each team up to date on what the other team is doing. Finally, our budget is a constraint. Our team was given a budget of $1,500. The project budget must stay under this value.

7.0 Project Plan / Scope

The following section is a detailed list of all major objectives or milestones that are to be achieved in the fall 2013 semester. A time frame and explanation of each task are shown below. The team Gantt chart has the same information and is attached on the back.

FALL 2013 SEMESTER OUTLINE (FSU)

Contact Sponsor and Meeting
- Planning time: weeks 1-4
- Sponsor: Dr. Juan Ordonez (jordonez@fsu.edu)
- Due: September 17
- Status: Complete

Code of Conduct
- Planning time: weeks 3-6
- Had to resubmit because of communication error
- Due: October 4
- Status: Complete

Ice Breaker Report
- Planning time: weeks 1-3
- Mechatronics
- Due: September 10
- Status: Complete

Needs Assessment
- Planning time: weeks 4-5
- Due: September 26
- Status: Complete

Initial Project Research and Brainstorming
- Planning time: weeks 2-4
- Research improvement to concentration and mass flow sensors
- Status: Complete

Project Plans and Specifications
- Planning time: week 7
- Due: October 11
- Status: Complete

Algae Growth
- Planning time: weeks 5- 16
- Started growth on September 27
- Must maintain the growth of two different algae's throughout the semester
- Status: In Progress

Sensor Test Section
- Planning time: weeks 7-9
- Due: week 9
- Status: In Progress

Initial Webpage Design

- Planning time: weeks 7-8
- Get initial website online
- Due: October 18
- Status: In Progress

Invention Disclosure

- Planning time: week 12-14
- Due: December 7
- Status: Not Started

Midterm Presentation

- Planning time: weeks 8-9
- Due: October 24
- Status: Not Started

Final Presentation and Report

- Planning time: week 14-15
- Due: December 5
- Status: Not Started

FALL 2013 SEMESTER OUTLINE (UFPR)

Contact Sponsor and Meeting

- Planning time: weeks 1-3
- Sponsors: Dr. Jose Vargas (vargasjvcv@gmail.com) & Dr. Juan Ordonez (jordonez@fsu.edu)
- Due: September 13
- Status: Complete

Initial Project Research and Brainstorming

- Planning time: weeks 4-7
- Research patents in Brazil and generate concepts for new addition/extraction units
- Status: Complete

Midterm Patent Presentation

- Planning time: weeks 4- 6
- Present plan for patent, current progress, and obtain feedback
- Status: Complete

Performance Specifications for Addition/Extraction Units

- Planning time: weeks 6-7
- Due: October 11
- Status: Complete

Patent Submission

- Planning time: weeks 4-8
- Due: week 8
- Status: In Progress

Project Feasibility Presentation in Brazil

- Planning time: weeks 6-8
- Present economic and technological feasibility of addition/extraction units

- Due: October 16
- Status: In Progress

Decision Matrix & Concept Selection
- Planning time: week 8
- Select at least 1 leading concept and 1 backup concept for detailed design
- Status: Not Started

Detailed Design
- Planning time: weeks 8-10
- Create detailed designs of addition/extraction unit prototypes and test cell to be built at UFPR
- Status: Not Started

Test Cell Construction
- Planning time: weeks 10-12
- Buy materials and construct test cell for testing new unit prototypes
- Status: Not Started

Addition/Extraction Unit Prototyping
- Planning time: weeks 10-12
- Buy materials and construct prototypes to be tested using the test cell at UFPR
- Status: Not Started

New Unit Testing
- Planning time: weeks 12-13
- Test new addition/extraction units on test cell
- Status: Not Started

8.0 Project Assignments

Each team member has been assigned a specific field within the project that they are responsible for. It is that team member's responsibility to be the lead engineer in his/her specified field. The following is a list of the project members followed by their roles.

Stephen Kassing
- *Lead Project Engineer*
- *Deliverable/Report Writer – writes project deliverables*
- *Web Developer – develops and maintains team website*
- *Invention Disclosure Lead – researches and files an invention disclosure through FSU*

Markus Dillman
- *Lead Algae Engineer – grows and maintains two types of algae*
- *Concentration Sensor Calibration Lead – takes lead on calibrating the sensor*

Diego Soler
- *Lead Mechatronics Engineer – leads improvement of mass flow and concentration sensor and*

- *Co-Lead of Addition/Extraction Units – co-leads the development of the addition/extraction units*

Matthew Vedrin

- *Lead international engineer (UFPR)*
- *Co-Lead of Addition/Extraction Units – co-leads the development of the addition/extraction units*
- *Report Editor – edits all deliverables and reports before they are submitted*

9.0 Fall Weekly Schedule

United States Group

This fall, the team members currently residing in the US will hold weekly video meetings with the team members currently residing in Brazil. The team members in Brazil include Matthew Vedrin, the FSU student currently at the Federal University of Paraná (UFPR), as well as supporting team members from UFPR. There are two scheduled meetings per week for the team in the US, one on both Tuesday and Thursday. However, it is at the discretion of the team leader to determine if both meetings are necessary and to notify the team members of any meeting changes. In these meetings the group will discuss upcoming events and new project details. Every other Wednesday, a biweekly video-conference is held with the team members in Brazil. The purpose of this meeting is to keep each group up-to-date on what the other is doing. Meetings with sponsors will be scheduled, when needed, at least 24 hours in advance.

Brazil Group

The team members in Brazil will meet two times per week on Mondays and Fridays. The weekly meeting times or dates may be canceled or changed at the discretion of the international team leader in concordance with the needs of the team members and project deadlines. In addition, they will participate in the bi-weekly conference calls held on Wednesdays with the team members in the US. Certain members of the team in Brazil will be required to participate in the mid-term and final group presentations via video-conference.

10.0 Equipment & Sensor Performance Specifications

The performance specifications are capabilities and performance characteristics that the equipment or sensors must satisfy in order to successfully meet the needs of the customer.

Performance Specifications of Concentration and Mass Flow Sensors

The following is a set of performance specifications for the mass flow and concentration sensors.

More specific details of each sensor are explained later in this section. It is important to note that the performance specifications for these sensors are targeted toward technology modifications, only, and are not intended to be used to completely redesign the previously developed sensors. However, new designs may be considered at the request of the customer.

- The mass flow and concentration sensors should be combined into one case (if possible).
- The sensor case should have its own source of energy so it does not need to be connected to a computer at all times.
- The sensors should be mobile, allowing them to be placed in various locations on any of the photobioreactors at FSU or UFPR.
- The sensors should have a method of viewing information and/or inputting commands on or inside the sensor case.
- The sensors should be able to store information or data that can be extracted without a direct cable connection to any other devices.
- If a single case contains both sensors, the size of the unit should be scaled such that it is still able to easily connect to and function on the existing photobioreactor systems.
- Any hardware additions or improvements to the sensors should be modular, minimal cost, and easy for persons of technical and non-technical backgrounds to operate.

Mass Flow Sensor

The mass flow sensor was designed last year to measure the flow through the photobioreactor. The mass flow is determined using equation 1 below. The general idea is that if a known heat is applied to the system, with a known specific heat and temperature change, the mass flow can be calculated. This semester, this sensor will be calibrated and improved.

$$\dot{Q} = \dot{m}\, C_P \Delta T \qquad (1)$$

Another alternative way to measure the mass flow rate is currently being examined by the design team. It uses ultrasound waves to send a signal into the flow. When the signal is returned, the frequency will be shifted because of the Doppler Effect. The amount of shift depends on the speed of the flow. This, combined with the concentration of the fluid, would allow us to calculate the mass flow.

Concentration Sensor

The concentration sensor was developed by last year's senior design team. It works by emitting light through the photobioreactor piping via light-emitting-diodes (LED's). The light, as it travels through the pipe and algae-water, hits a Light Dependent Resistor (LDR) on the other side. By observation under a microscope, the actual concentration of algae can be determined. This value, used with the resistance measured from the sensor, allows us to calibrate the sensor to an accurate reading of algae concentration. This year, the team will work on improving the functionality and accuracy of this sensor. The possible improvements are listed below.

- The accuracy of the sensor can be improved by adding another photo resistor on the Wheatstone bridge to double the sensitivity. The Wheatstone bridge converts the variation on resistance of the sensor into voltage.
- Another possibility is to replace the photo-resistor sensor with a photo-transistor sensor (IR-Sensor) which can read a more narrowed range of frequencies, leading to less noise interference in the sensor's readings.

Automatic Addition/Extraction Units

Every photobioreactor system currently existing at UFPR or FSU operates on a batch system. A batch system requires a photobioreactor to be shut down while algae are extracted, pipes are cleaned, and new nutrients or algae are added to the unit. This type of operation reduces the potential productivity of the entire system. The development and implementation of automatic media-addition and algae-extraction units, in combination with the use of the concentration and mass flow sensors, would allow the photobioreactors to operate continuously – i.e. without periodic shutdowns for extraction/addition – while ideally keeping the algae at a constant exponential growth rate. Thus, these units would greatly increase a photobioreactor's potential output rate of biomass. Similar systems often used in chemical processes include a "chemostat" and "turbidostat". These systems will be studied and used as base technologies for understanding the requirements of the desired units. The performance specifications for the addition/extraction units are listed below:

- The pressure of the fluid being added to the photobioreactor must exceed the pressure of the fluid inside the photobioreactor at the point of addition (in order to create an inward flow).
- The pressure of the fluid being extracted from the photobioreactor must exceed the pressure of the fluid, or lack thereof, outside of the photobioreactor at the point of extraction (in order to create an outward flow).
- The units must be attachable and detachable in a non-permanent fashion to any photobioreactor system existing at UFPR or FSU.
- The units must be able to automatically determine the proper amounts of algae-extraction and media-addition that are needed to maintain a constant concentration of algae inside the photobioreactor.
- The units must include liquid storage areas where either the algae or media solution can be temporarily held if the customer desires or if dependent processes require intermediary storage (such as the use of a non-continuous flocculator).
- In the case of intermediary storage, the extracted algae must be agitated sufficiently to reduce sedimentation or sticking to storage tank walls.
- The pressure of the fluid being added to the photobioreactor must not harm the cells.
- The extraction unit must not cause cavitation in the system.
- The size of both units should be such that the units are easily moveable and only require a single person to operate under manual conditions.
- The cost of the units must be minimal and within the budget of the project.
- The units should require minimal maintenance and as little expertise as possible to operate.

Sensor Test Unit

A small testing unit will be built to model a system similar to the photobioreactor. Currently, in order to test and calibrate the sensors, the group must wait up to two months for enough algae to grow to fill the photobioreactor. Once the test unit is built, the group will be able to start testing and calibrating immediately. A few performance specifications are listed below. Construction of this test unit will take approximately two weeks. Designs have been presented and are currently under review.

- The test unit must model and simulate all conditions similar to the photobioreactor.
- The test sections should be interchangeable, allowing different sensors and materials to be attached.
- The mass flow sensor, concentration sensor, and addition/extraction units should be able to be attached to the test unit.
- The unit should have a pump to establish a constant flow.

11.0 Algae Cultivation

A very specific process is required to effectively cultivate algae. The microalgae are first bought in a small vial, containing approximately 27mL of algae and growth media. Everything that comes into contact with the algae in any way has to be clean and contamination-free because algae are extremely vulnerable to micro bacteria at an early stage. The algae and necessary nutrients, which the algae need for growth, were purchased from Carolina Biological Supply Company (Carolina). Four vials of two different types of algae were received, two vials of each kind. One species is of the Scenedesmus genus and the other is of the Chlorella genus. Among the four samples of algae, two methods of cultivation are being used. One method is from the operations manual provided by Carolina and the other follows similar procedures used at UFPR in Brazil, and is being provided by a current graduate student at UFPR. So far, the methods used in Brazil seem to be working better than the ones from Carolina. In about two weeks, subcultures will be made and will increase the total volume of algae from 1L to 6L. After another four weeks, an additional subculture will be made, increasing the amount of algae to nearly 30L. This will yield about 2-3L for each culture from batch one and about 500mL for each culture from batch two.

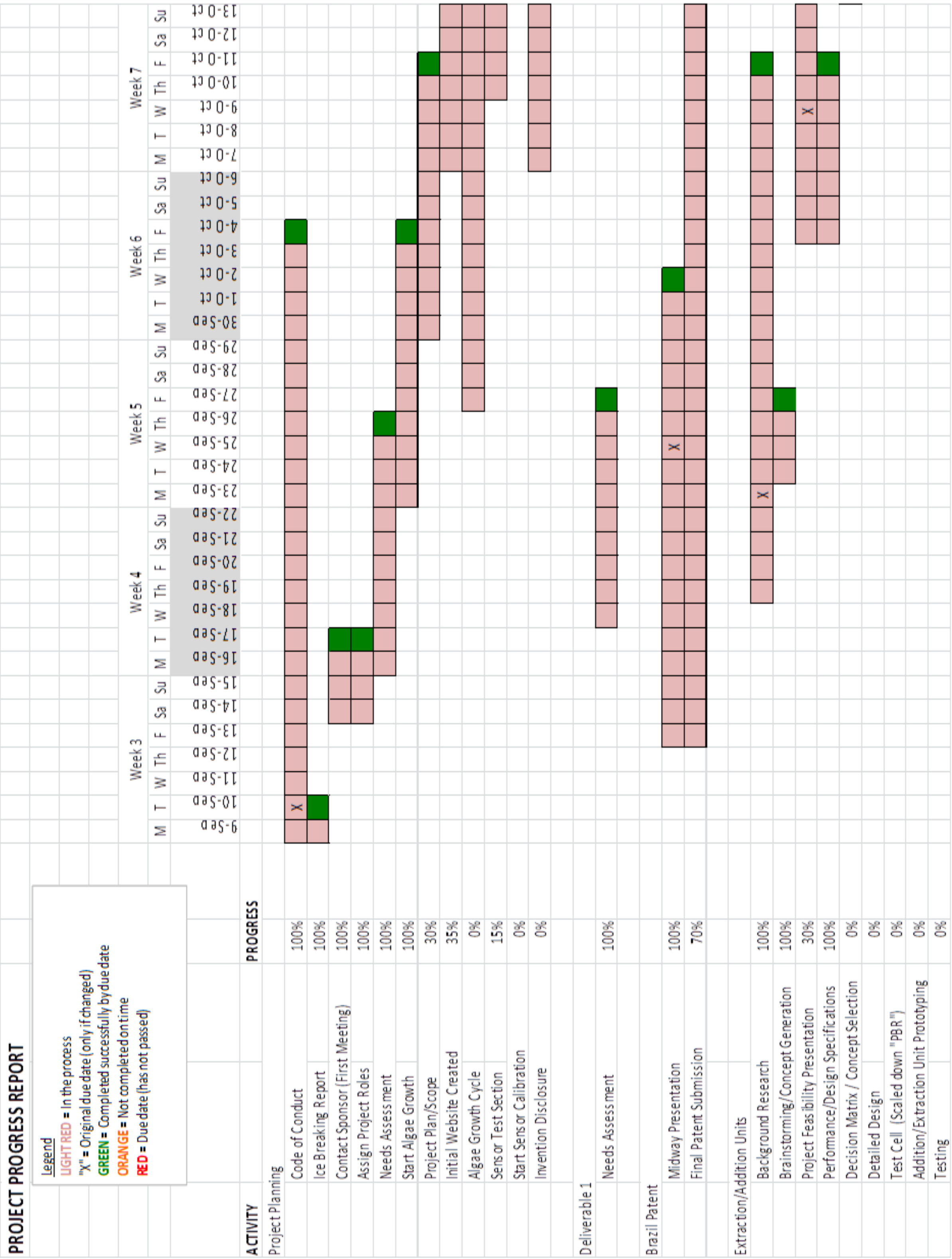
At the current rate, enough algae media should be available to fill the photobioreactor by December or at the latest by January for batch two. Batch one is on a faster growth cycle so it can be used in the test section that is being made. This will simulate normal operational conditions that will be experienced in the photobioreactor. Batch two is growing slower but is expected to be of greater quality, overall, so it should be used very lightly since it will meet all the requirements that the sensors will need to be used effectively.

12.0 **References**

1) Chisti, Yusuf. *Bio Diesel from Microalgae*. N.p.: Biotechnology Advances, n.d. Print.

2) Ordonez, Juan C., and Jose Vargas. "Senior Design Proposal, 2013-2014." FSU and UFPR, n.d. Web. 26 Sept. 2013.

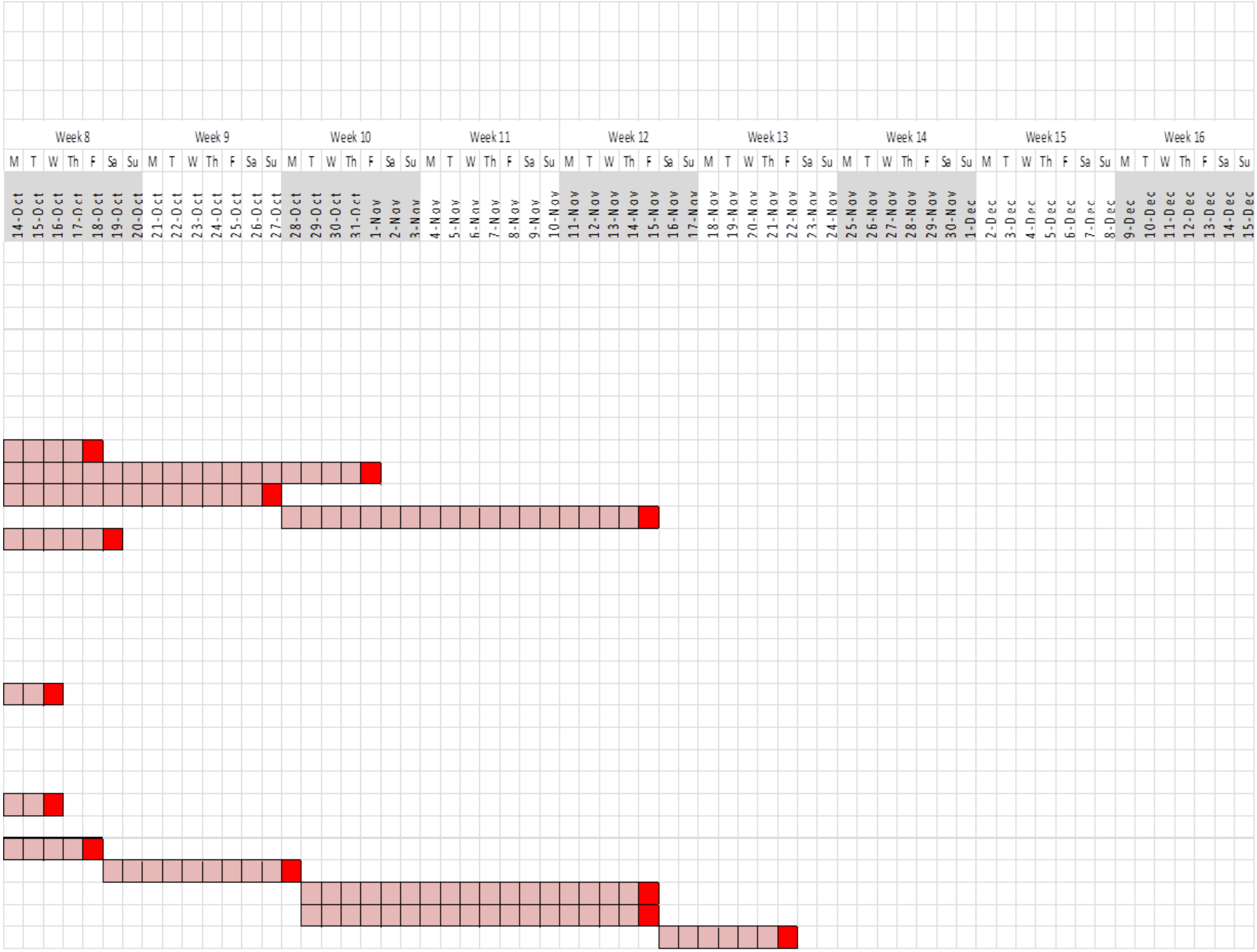
Gantt Chart



PROJECT PROGRESS REPORT

Legend
LIGHT RED = In the process
"X" = Original due date (only if changed)
GREEN = Completed successfully by due date
ORANGE = Not completed on time
RED = Due date (has not passed)

ACTIVITY		PROGRESS
Project Planning		
	Code of Conduct	100%
	Ice Breaking Report	100%
	Contact Sponsor (First Meeting)	100%
	Assign Project Roles	100%
	Needs Assessment	100%
	Start Algae Growth	100%
	Project Plan/Scope	30%
	Initial Website Created	35%
	Algae Growth Cycle	0%
	Sensor Test Section	15%
	Start Sensor Calibration	0%
	Invention Disclosure	0%
Deliverable 1		
	Needs Assessment	100%
Brazil Patent		
	Midway Presentation	100%
	Final Patent Submission	70%
Extraction/Addition Units		
	Background Research	100%
	Brainstorming/Concept Generation	100%
	Project Feasibility Presentation	30%
	Performance/Design Specifications	100%
	Decision Matrix / Concept Selection	0%
	Detailed Design	0%
	Test Cell (Scaled down "PBR")	0%
	Addition/Extraction Unit Prototyping	0%
	Testing	0%


Week 8
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Week 9
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Week 10
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Week 11
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Week 13
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Week 16
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