Hydrogen from Microalgae and the Collection and Sensing Systems

Team 9

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TABLE OF CONTENTS

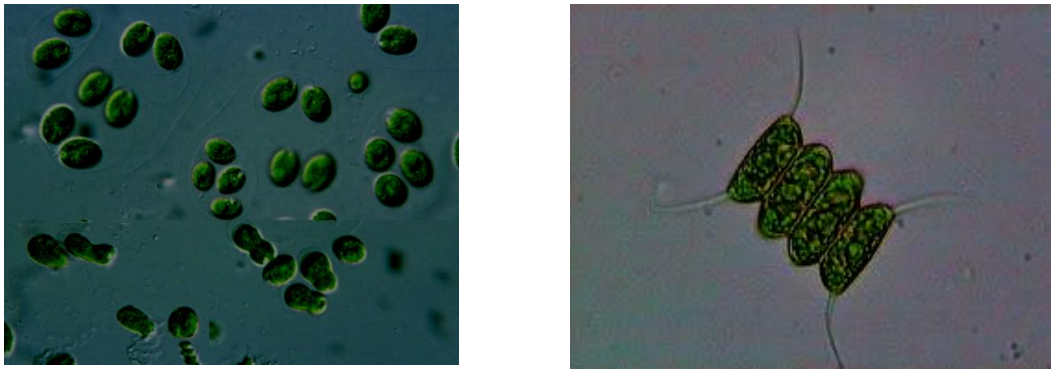
ABSTRACT

Although it may not be readily apparent, energy directly correlates with the quality of life and technological resources that are available to people. As societies grow and become more advanced, the consumption and need for more energy increases. The augmented demand can put a strain on available resources, which is why there has been a heightened interest in alternative energy. This project will focus on hydrogen as an alternative energy source. A photobioreactor has been developed to aid in the production of hydrogen gases by allowing for a controlled environment. This controlled environment creates conditions in which the microalgae strains *Chlamydomonas reinhardtii* and *Scendesmus sp.* can steadily create hydrogen gases. With a steady, self-sustainable hydrogen production, the hydrogen gases are able to be used in applications to create energy, such as fuel cells. This project seeks to improve microalgae cultivation and develop a sensor to accurately measure the amount of hydrogen production. Under optimal conditions, hydrogen output is expected to be $10.2\frac{mL}{h}$ for *Chlamydomonas reinhardtii* and $0.167\frac{mL}{h}$ for *Scendesmus sp.* After comparing the amounts of hydrogen to be produced, a focus on the *Chlamydomonas reinhardtii* strain was established.

I. INTRODUCTION

Hydrogen gas has become an ideal fuel source for the future. This notion is backed by the facts that hydrogen gas burns cleanly and generates a large amount of energy per unit mass allowing it to be more fuel-efficient than other resources [1]. Using hydrogen in renewable energy processes has become of greater interest due to the depletion of natural oil reserves. However, because of low concentrations at its pure form, hydrogen is not cost efficient for everyday use, making the study of biohydrogen one of great interest [2]. This calls for a further exploration of hydrogen generation as a waste product of the anaerobic respiration of green and blue algae, especially when the algae strains are used in a photo bioreactor. When a controlled environment enables and regulates the proper anaerobic conditions necessary for the cultivation of algae, a photobioreactor is constructed to allow larger amounts of biohydrogen to be produced and utilized as clean energy [3]. This occurs through biophytolysis of water by algae. The presence of light irradiation catalyzes the event and water is broken down into its hydrogen and oxygen components [4]. The phenomenon in which hydrogen is created as a waste product during the photosynthesis of algae must be promoted in a way that overcomes various issues [5]. These issues include creating a system that enables steady and continuous microalgae growth that is cost effective. The evolution of hydrogen results in an amount of fuel that is useable in commercial applications. The scope of this project will be directed toward the design and development of microalgae and measuring and collecting the hydrogen produced.

In today's world the need for renewable/sustainable energy has never been greater. Coal, petroleum, and other types of non-renewable sources provide much of the energy used today. Within the next century, these energy resources are projected to be fully depleted. Hydrogen is at the top of the list of biofuels that can solve the energy crisis that future generations face. Hydrogen in the simplest element known to man and it is usually combined with other elements. For example, hydrogen combines with oxygen to form H_2O, the most abundant resource on our planet [1]. However, it has proven difficult and expensive to split hydrogen from water to use as an energy source [2]. The most common form of this element is found as hydrocarbons, a product of organic compounds, which makes up gasoline, methanol, and propane. Hydrogen can be extracted from hydrocarbons through the application of heat, a process known as reforming [1]. The downside of reforming is the byproduct CO2, which contributes to the greenhouse effect. One alternative for hydrogen production comes from algae. Using sunlight as their energy source, and under the right conditions, algae can give off hydrogen. The research that is currently being done is aimed at two types of algae*: Scenedesmus sp.* and *Chlamydomonas reinhardtii*, Figure 1a and 1b, respectively. These types of algae are favored due to their high degree of adaptability and fast reproductive cycle [3]. Our sponsor has given us the primary tasks of designing and developing an H_2 producing photobioreactor, and designing and developing an electronic H_2 mass measuring sensor to test such systems.



(a) **(b)**

Figure 1: (a) *Scenedesmus sp.* (b) *Chlamydomonas reinhardtii*

In order to produce H_2 from algae, the algae must be cultivated in a controlled manner. There are two ways to cultivate algae: open ponds and photobioreactors. Photobioreactors (PBRs) are closed systems that provide a

controlled environment where algae productivity is high. PBRs are used to better control CO_2 supply, water supply, temperature, etc. [4]. Figure 2 shows a basic schematic of a PBR. The main components of such a system include a light source, hot plate, thermocouple, container, and a gas collection apparatus. Previous senior design teams at Florida State University have built working photobioreactors. One such team was team 7 from 2013 who was successful in designing and fabricating a bioreactor, which can be seen in Figure 3. Their bioreactor has sensors that can monitor algae concentration, mass flow rate, and CO_2 concentrations. The bioreactor is installed in the AME building.

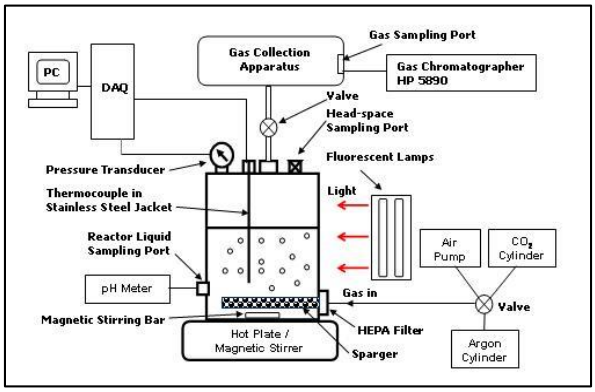


Figure 2: Schematic of a Photobioreactor.

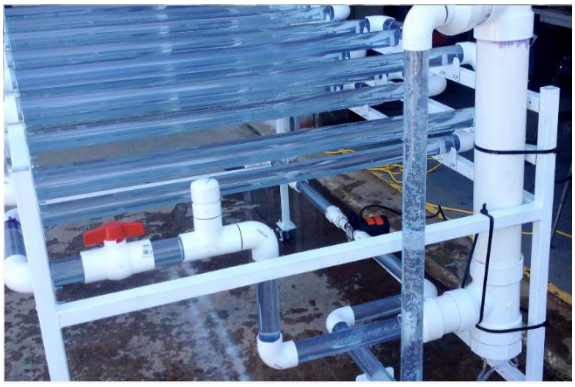


Figure 3: Team 7's 2013 photobioreactor

II. PROJECT DEFINITION

The primary goal of this project is to successfully complete the objectives and goals provided by the sponsor, Florida State University and the Federal University of Parana. After meeting with our sponsors, there were several changes made to the project objectives. These were made in the best interest of the project. The needs, goals, and objectives of this project are stated below.

A. Need Statement

Florida State University and the Federal University of Parana have joined together to sponsor this project. However, for this spring semester, the students studying at the Federal University of Parana will be working on the project at Florida State University. This will promote more concise communication and enable more frequent meetings. There is need for a scalable and sustainable process for producing hydrogen from microalgae cultures such as *Scenedesmus sp.* and *Chlamydomonas reinhardtii* to demonstrate the feasibility of photobioreactors in the field of alternative energy. Additionally, an automated sensing system will be needed to monitor the hydrogen content of the resulting PBR system.

B. Goal Statement

The goal of this project is to further the development of alternative energy with the use of a sustainable process for producing hydrogen from microalgae. To consider this project as successfully completed, the project sponsor provided several objectives that need to be met.

C. Objectives and Sponsor Requirements

The sponsors of this project include Florida State University and the Federal University of Parana. They have asked that we pursue and complete the following general project and prototype objectives:

Old General Project Objectives

- Design and construct operational H_2 producing units
- Design and construct an electronic H_2 measuring sensor
- Provide enough experimental data to test the operation of the H_2 producing designed units
- Provide mechanical drawings of the entire system and sensor for future product scale up

- 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 H_2 producing photo bioreactor system developed

After discussion with team sponsors and advisors, the new project objectives listed below were created. Some of the changes made to the general objectives listed above also had to be modified. Mechanical drawings for large-scale implementation along with the invention disclosure and patent request will not be done, primarily due to time constraints. After meeting with the advisors and sponsors of this project, it was decided that the new project objectives listed above encompass the true goals of all parties. However, it is advised that future teams attempt to complete the objectives omitted by this year's senior design team.

New Project Objectives for Spring 2015 Semester

- Modify the prototype built by the 2013-2014 Senior Design team for hydrogen production and continuous operation.
- Produce hydrogen from the algae species Scenedesmus and *Chlamydomonas reinhardtii* using a pre-fabricated small-scale airlift photobioreactor.
- Construct and test electronic H_2 and sulfur measuring sensors that will be implemented in the modified design.
- Provide mechanical drawings for the entire system.
- Implement an addition and extraction port to create continuous operation.

III. CONSTRAINTS

There are many changes and additions that had to be made to the prototype built by the 2013-2014 design team. Some of these modifications include:

- Reduction in the height of the bioreactor
- Reduction in the down-comer cross-sectional area
- The addition of a gas separator section.
- Hydrogen purification through the use of an oxygen filter.
- Electronic hydrogen gas and sulfur sensors.

A. Design Specifications

Due to time and budget constraints, it was advised to implement the photobioreactor prototype built by the 2013-2014 senior design team 7. Team 7 sought to develop a photobioreactor for biomass production and CO_2 sequestration.

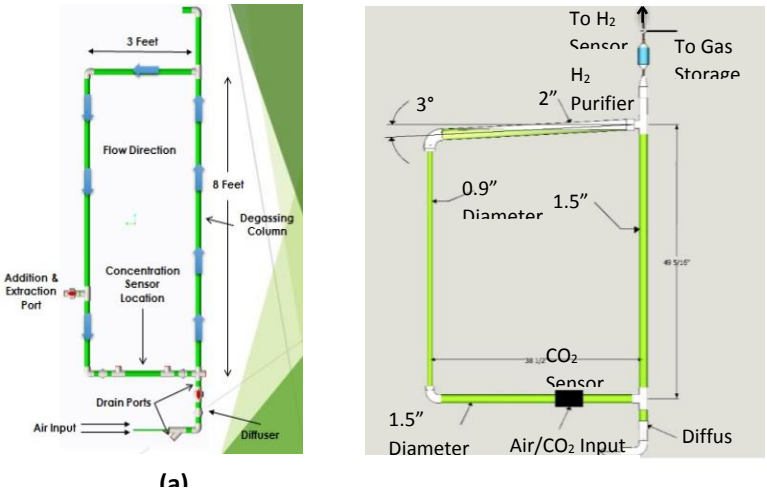


Figure 4: (a) Final design from 2013-2014 Senior Design Team (b) 2014-2015Senior

Because their photobioreactor design was based around this, appropriate changes had to be made. A comparison between the two designs is shown in Figure 4 (a) and (b).

The current photobioreactor design implements a gas separator where gas exchange occurs. The height of the reactor was reduced from 8 feet to roughly 4 feet in order to artificially light the bioreactor and to reduce the pressure needed for optimal superficial gas bubble velocity. The gas bubble velocity for *Chlamydomonas reinhardtii* was determined using a max shear stress of 0.01 Pa and assuming that shear velocity is 0.1 of the mean flow velocity. No shear stress values were found for *Scenedesmus sp.* The maximum gas bubble velocity for *Chlamydomonas reinhardtii* was found using the equations below, where v_{shear} is the shear velocity, τ is the shear stress in an arbitrary layer of fluid, and ρ is the density of the fluid.

$$v_{shear} = \sqrt{\frac{\tau}{\rho}} = \sqrt{\frac{0.01\ Pa}{999.97\ \frac{kg}{m^3}}} = 0.00316\ \frac{m}{s} \qquad \textbf{(1)}$$

$$v_{gas} = 0.00316 * 10 = 0.0316\ \frac{m}{s} \qquad \textbf{(2)}$$

Another important geometric parameter that impacts the light utilization efficiency of algae is the surface area to volume ratio of the reactor. A larger value results in better light utilization. The surface area to volume ratio was determined using the following equation and using an average diameter of 1.5 in:

$$\frac{A}{V} = \frac{2\pi rl}{\pi r^2 l} = \frac{2}{r} = \frac{4}{d} = 2.67/m\ , \qquad \textbf{(3)}$$

where *A* is the surface area of the bioreactor, *V* is the volume of the bioreactor, and *r* is the radius, *d* is the diameter, and *l* is the length of the PVC piping.

For large scale applications, the ratio of the cross-sectional area of the down-comer to riser is extremely important. The down-comer is responsible for the downward travel of fluid and gas from the top of the bioreactor. Conversely, the riser transports fluid and liquid to the top of the bioreactor. A reduction in area for the down-comer (left vertical tube) is an important parameter that affects gas holdup, CO_2 mass transfer, and hydrogen output.

$$\frac{A*d}{A*r} = \frac{\pi {r_d}^2}{\pi {r_r}^2} = \frac{{r_d}^2}{{r_r}^2} = \frac{0.9^2}{1.5^2} = 0.36 \qquad , \qquad \textbf{(4)}$$

where *A* is the surface area of the bioreactor, *r* is the radius of the PVC piping, *d* is the diameter of the PVC piping, r_d is the radius of the down-comer, and r_r is the radius of the riser.

The H_2 sensor is composed of a MQ-8 sensor and an Aurdino uno microcontroller. It will measure the percent concentration of hydrogen within a beaker. The volume output of hydrogen will then be calculated from:

$$V = \frac{c*V_c}{V_R*t} \qquad , \qquad \textbf{(5)}$$

where *c* is the percent concentration of H_2, V_C is the total volume of the measuring container, V_R is the volume of the solution and the algae in the photobioreactor, and *t* is the time required to reach the percent concentration.

Circulation of the algae throughout the photobioreactor must occur in order for the algae to survive, which can be done by a commercial air compressor. The same air compressor used by the 2013-2014 design team will be used for the proposed prototype. This air compressor has a 1-gallon capacity, operates at 100 psi and 240 Watts. The compressor includes a pressure regulator, which will be used so that the bubble size and velocity will not produce a shear stress greater than the maximum shear stress that the algae can be subjected to. In order to purify the hydrogen gas that is produced from the algae, a disposable oxygen filter will be attached at the outlet of the degassing column. The in-line purifier removes oxygen from inert carrier gases down to less than 50 ppb. It can purify a volume equal to 4 to 5 standard cylinder of 300 cf. This purifier will also remove moisture, and organic contaminants. The purifier's dimensions are 5.5" long by 2.5" in diameter.

B. Performance Specifications

The hydrogen mass sensor must have three different colored LED lights that correspond with different percentage levels (5%, 10%, 20%) of hydrogen mass. The lights will light up according to the mass percentage detected. It will also make a sound once the hydrogen mass percentage level is above 5%. In order to optimize hydrogen output and bioreactor performance, a minimum of 1 gallon of algae must be grown and placed into the photobioreactor.

IV. METHODOLOGY

Creating a set schedule and organization of tasks is essential to ensuring a successful project. The first task included researching microalgae. It is important to understand how to grow and maintain healthy algae so that enough hydrogen will be produced. Without a substantial amount of hydrogen, testing will be inadequate. Algae will initially be grown in small beakers so that it can be more carefully monitored. Data will be collected periodically in order to determine how well the system is working. Once roughly a gallon of algae is grown, it will be transferred to the photobioreactor. Team members have also worked on designing and calibrating a sensor which will aid in determining the amount of hydrogen being produced by the microalgae. The hydrogen sensor will be routinely tested on purchased hydrogen gas to determine if the readings are correct and if any calibrations need to be made. The collected results will be analyzed and used to determine how the current system can be improved. The final results and suggestions for improvement will be presented during the final presentation.

A. *Schedule*

The Gantt chart for the spring 2015 semester is shown in Appendix A. Activities for this chart began at the beginning of this semester as opposed to earlier in the month due to complications with ordering some of the required items. For instance, the algae that was ordered died when it was picked up by one of the members and, therefore, needed to be reordered. This could only happen once the semester had begun due to the hours of operation of the AME building. Furthermore, amendments to certain aspects of the project made during a meeting with the sponsors of this project and Dr. Gupta called for other components to be added to the system in order to complete the design for this year's team. As a result, more items needed to be ordered and tested. The Gantt chart in Appendix A is broken down into four categories to make the chart easier to read:

Gaining Access to Lab – In order to complete this senior design project, access to various resources that are present in the CAPS building where one of the advisors to this team is currently working is needed. Many resources such as pumps, tubing, space, etc. have been provided by the lab at no cost which further help our team stay within our specified budget. The lab is adjacent to the FAMU-FSU College of Engineering so the status of this project can be checked on a daily basis by at least one person in the group.

Photobioreactor (PBR) – All of the tubing and fittings for the photobioreactor were ordered earlier in the semester so once the parts arrive to the AME office, the photobioreactor, independent of the sensors, will be constructed. This part of the design should not take more than a few days to complete. Once the photobioreactor is completed, it will then be tested to make sure the components are connected correctly in order to prevent leaks in the system once the algae has been added. After the preliminary testing of the photobioreactor has been completed, any adjustments that the system needs will be made.

Algae – The algae that was reordered at the beginning of semester will initially be grown in beakers or any other viable containers present in the lab until a large enough batch to be transferred to the photobioreactor has been cultivated. During this growth stage, various observations will be made in order to gather information needed to help calibrate the sensors that will be integrated into the photobioreactor. The hydrogen sensor will also be used after a certain amount of time to measure any
Hydrogen gas output that might have resulted from the growth of the algae. Once a large enough batch has been cultivated, it will then be moved from the beakers to the PBR to operate on a more continuous and automated scale. Algae growth and production of hydrogen gas will be studied and analyzed along with the performance of the PBR.

Sensors – Along with a hydrogen sensor, a mass concentration sensor and a sulfur sensor may be implemented into the system in an attempt to make the design more automated. The parts to the sensors are ordered and assembled to form the necessary sensors. Once the sensors are assembled, they will be coded, tested, and then calibrated using data gathered during the initial growth stages of the algae. Once the sensors have been properly calibrated, they will be integrated into the photobioreactor in order to complete the system.

V. CONCLUSION

The continuous development of renewable energy sources like that of hydrogen can make a positive impact on society. Decreasing society's dependency on fossil fuels will not only create a cleaner atmosphere by reducing greenhouse gas emission, but it is also an economically viable energy option. This design project is focused on developing a more efficient way of cultivating microalgae as well as maximizing the amount of hydrogen that is produced and extracted in order to develop an effective energy alternative. The design will incorporate a photobioreactor, hydrogen gas purifier, hydrogen gas sensor, and storage. Due to budget and time constraints it was necessary to use the prototype from the 2013-2014 senior design team. This design was chosen because of its simplicity and the fact that it is an airlift bioreactor, which has the advantages of good mixing, effective mass transfer of CO_2, high surface area to volume ratio, and good removal of O_2. However, several modifications had to be made so that the photobioreactor could be optimized for hydrogen gas output. Two important characteristics of the proposed design include the surface area to volume ratio and the cross sectional area ratio between the down-comer and riser with values of 2.67 in^{-1} and 0.36, respectively. It was also necessary to calculate the maximum

velocity of the gas bubbles produced so that the shear stress the algae are subjected to does not break them up apart. The max mean bubble velocity calculated in this case was 0.0316 m/s.

The hydrogen gas sensor that will used is an MQ-4 hydrogen gas sensor with a sensitivity of 100 – 10,000 ppm and is controlled through an Arduino Uno microcontroller board. A prototype of the sensor has been built and programmed at UFPR. However, the sensor must be rebuilt, tested, and calibrated at Florida State University. When hydrogen is present, the system will alert the user through a chain of LEDs that light depending on the percent concentration, e.g. one LED for 5% concentration, two LEDs for 10% etc. The hydrogen output of each strain, *Scenedesmus sp*. and *Chlamydomonas reinhardtii*, will be calculated from the percent concentration, the total volume of the beaker, the total volume of the algae cultivated, and the time needed to reach the percent concentration detected. Large-scale implementation of the proposed design will be looked into during the spring semester.

VI. REFERENCES

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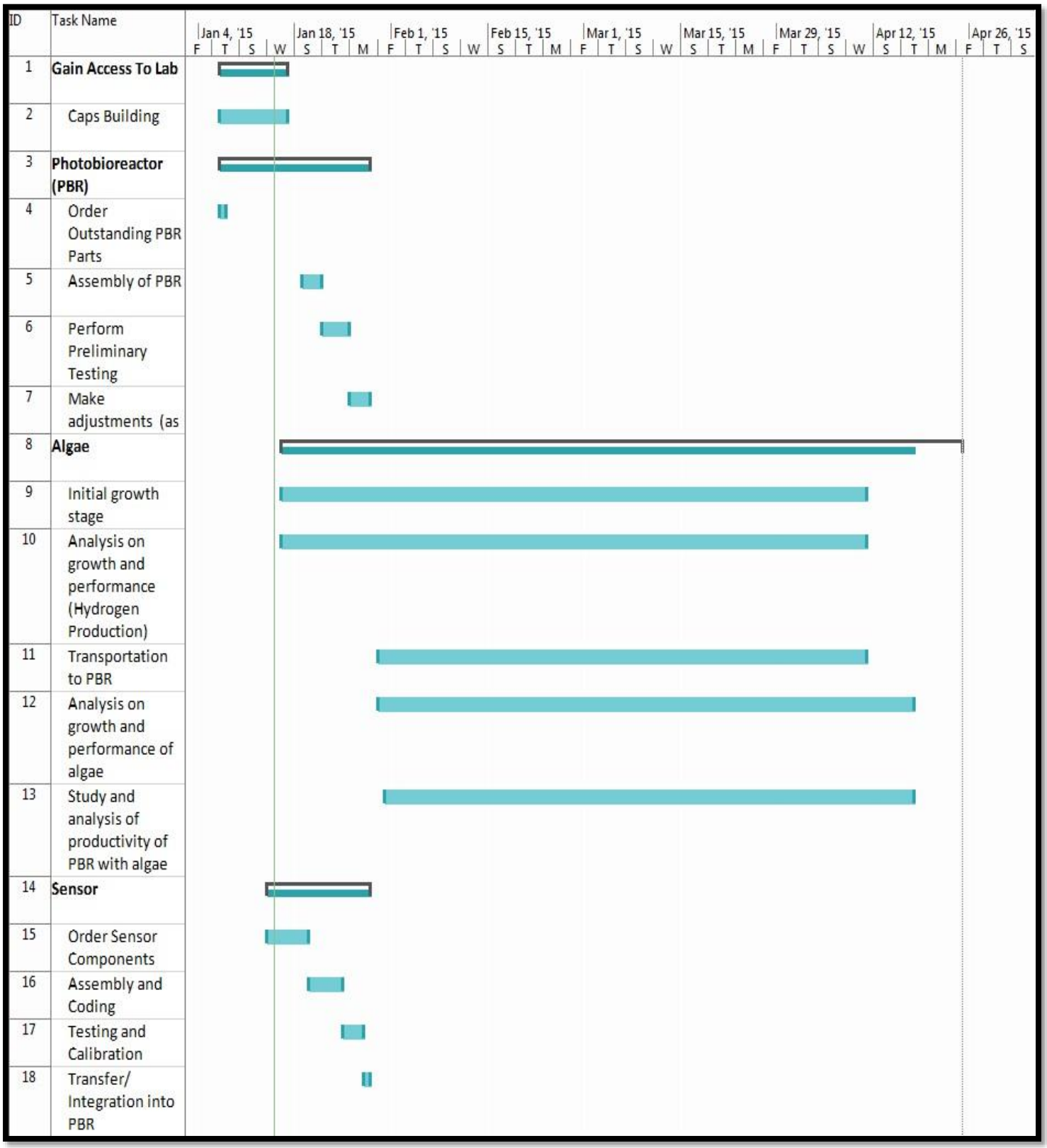
APPENDIX A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Task Name
Jan 4, '15
Jan 18, '15
Feb 1, '15
Feb 15, '15
Mar 1, '15
Mar 15, '15
Mar 29, '15
Apr 12, '15
Apr 26, '15
1 Gain Access To Lab
2 Caps Building
3 Photobioreactor (PBR)
4 Order Outstanding PBR Parts
5 Assembly of PBR
6 Perform Preliminary Testing
7 Make adjustments (as
8 Algae
9 Initial growth stage
10 Analysis on growth and performance (Hydrogen Production)
11 Transportation to PBR
12 Analysis on growth and performance of algae
13 Study and analysis of productivity of PBR with algae
14 Sensor
15 Order Sensor Components
16 Assembly and Coding
17 Testing and Calibration
18 Transfer/ Integration into PBR