The Kuwaiti Company

Northern Arizona University, Flagstaff, Arizona

December 16th , 2015

Client

Kevin Davidson

Hualapai Tribe Planning & Economic Development Director

Technical Advisor	Grading Instructor
Dr. Terry Baxter	Bridget Bero

Dear Kevin Davidson,

P2BK is grateful for the opportunity to analyze and research the conversion of algae waste, provided by the Hualapai nation, into bio-fuel. In the report details the technical analysis and recommended alternatives for the project. If there are any further questions or concerns, please contact the project managers Saleh Ahmad, Khaled Jaber and Abdullah Zakareia at soa8@nau.edu, kwj7@nau.edu and amz64@nau.edu.

Sincerely,

The Kuwaiti Company

Saleh Ahmad, Abdullah Zakareia and Khaled Jaber

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Acknowledgements

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1.0 Project Description and Background

The Hualapai Lagoons project is intended to study and analyze the possibility of converting algae in the wastewater lagoons to bio-fuel. The 5 lagoons are located in Peach Springs, Mohave County, in the northwest of Arizona as shown in Figure 1.1 below. The lagoons are on the southwest end of the city, with close proximity to Burlington Northern Santa Fe Railroad and Highway 66 (Fig1.2). The population of Peach Spring is 1,010 people (2010 count). The flow rate of wastewater to the lagoons is 1,000 gallons per day as provided by the client.

Figure 1: Peach Spring Map.

Figure 2: 5 Lagoons.

Figure 1.2 above show a top view for the ponds, where only pond 1 and 2 that are circled in red are the ponds that are covered with lined tar rolls. On the other hand, ponds # 3,4, and 5 are not sealed where there are some plants, which will reduce the nutrients that the algae needs to grow. The weather in Peach Springs fluctuates during the entire year. The winter temperatures can reach lows of 9 Fº, in the summer it can reach a high temperature of 113 Fº. During the winter and spring seasons, the precipitation and snowfall rates are significant, however, they are below the United States average. The average precipitation is 8.88 inches per year and the average snowfall is at 0.72 inches per year. Table 1.2 shows the maximum, minimum and average temperatures of Peach Springs, as well as the average rainfall and snowfall throughout the year.

Table 1: Dimensions of ponds.

Pond#	Length ft	Width ft	Area ha	Volume L
1	317.40	278.25	0.8204	12504230
2	202.29	248.94	0.4678	7129910
3	353.29	211.81	0.6951	10594798
4	563.08	217.22	1.1363	17317484
5	522.93	220.90	1.0732	16355136

Table 1.1 shows the dimensions of each pond, including Area, width and volume.

Table 2: Weather in Peach Springs.

Month	Temp. (Min) ˚F	Temp. (Max) ˚F	Temp. (Avg.) ˚F	Average Rainfall(Inches)	Average Snowfall(Inches)
January	9	73	43	0.64	3.9
February	20	73	46	1.1	2.1
March	21	90	52	0.35	1.2
April	25	94	59	0.44	0.4
May	32	103	72	0.13	1
June	46	106	80	0.02	0
July	57	113	86	0.69	0
August	54	107	83	0.71	0
September	45	104	76	0.61	0
October	29	93	63	0.6	0
November	18	86	54	0.67	0

December	11	73	41	0.97	2.5
Average	27.8	97	75	10.6	2.7

Table 1.2 shows the weather in Peach Springs. The ponds are located outside and open, where weather has a huge effect in the algae growth.

1.1 Technical Considerations

Technical work required for the project includes algae characterization of the algae species and determination of the annual algae mass production. The project was originally intended to see if sufficient quantities of algae are available for feasible conversion to bio-fuel and if that was the case, a feasibility study of algae to bio-fuel options will be performed. However, due to the lack of data available and the need to have more data of the ponds, especially during peak season, the project has transformed into a research project, involving finding information about the lagoons' condition during the season that the data was taken. In addition, options to enhance the existing algae growing conditions will be presented to benefit any potential future projects on the lagoons. Several algae growth conditions must be considered to obtain optimal results for algae growth, these conditions are light, pH, aeration, mixing, temperature and salinity.

1.2 Stakeholders

The main stakeholders of this project are the people of the Hualapai Nation. As the project stakeholders, the people want to manage the wetlands for the most productive uses possible.

2.0 Testing/Analysis:

2.1 Sampling:

The team collected samples throughout two trips to the location. The first trip took place on February 2015, where the team practiced taking samples, and gained the knowledge about the safety procedure and the procedure of collecting samples in the correct way. After that the second trip took place in September, 2015. The team collected samples in the second trip following the safety procedures and analyzed the samples at the ENV labs at NAU. The samples were collected using sample bottles and a rod by simply dipping the bottles into the ponds and filling them with the wastewater. From the second trip 11 samples were collected from the 5 ponds. The samples were collected from the top and the bottom of each pond. There were many types of algae found in the pond. Table 2.1 below presents the types of algae and their oil content percentage.

Table 3: Algae Oil Percentage.

Algae Type	Algae Oil Content (%)
Chlorella Vulgaris	38
Euglena	24.6
Coelastrum	43.2
Sphaerocystis	45.94

Table 2.1 above shows the different percentage of oil content for each algae type found in the samples. The most algae oil content was available in Coelastrum and Sphaerocystis. However, the content of algae oil percentage of Chlorella was used in the calculation of lipid production as the Chlorella was found in the ponds with a rate of 50% of the samples.

2.2 Identifying algae species

Algae samples from the lagoons were evaluated in the NAU, ENV lab by the microscope. Algae species identified were, Coelastrum, Sphaerocystis, chlorella, and Euglena. Euglena is considered as a microalgae, which is known for its smaller size than macro-algae. Figure 2.1 below shows a picture of the Coelastrum algae.

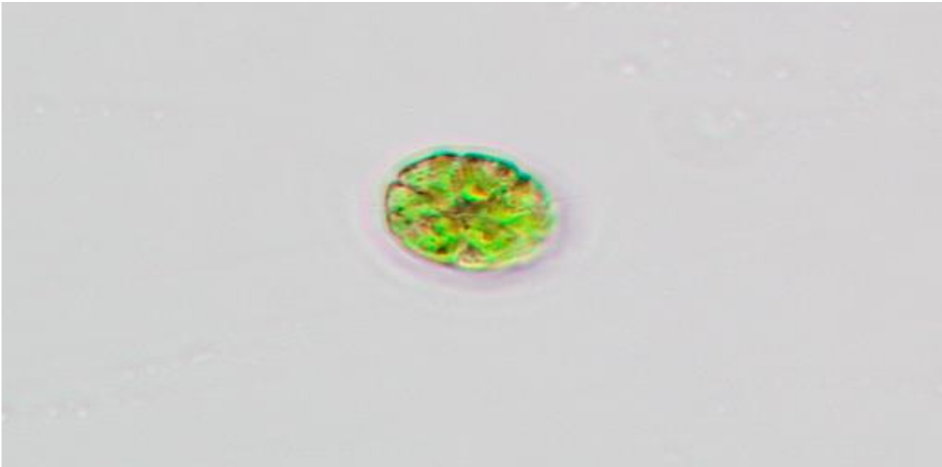


Figure 3: Coelastrum Algae. (Photo Credit Dr. Terry Baxter)

Table 4: Algae Species Percentage in Sample.

Algae Species Identified and Population Percentage	
Algae specie	Percentage
Coelastrum	~5%
Sphaerocystis	~5%
Chlorella	~50%
Euglena	~40%

The type of algae that was most present in the lagoons was Euglena. Euglena is considered as microalgae, which is known for its smaller size than microalgae. Having microalgae would make harvesting algae harder. On the other hand, Coelastrum, which is green algae, was found on the surface of pond#1. In addition, sphaerocystis is considered as green algae that was found on the surface of pond# 2. Moreover, Chlorella was found in the bottom of pond #3, which is considered as green and microalgae.

Figure 5: Sphaerocystis Algae (Photo Credit Dr. Terry Baxter)

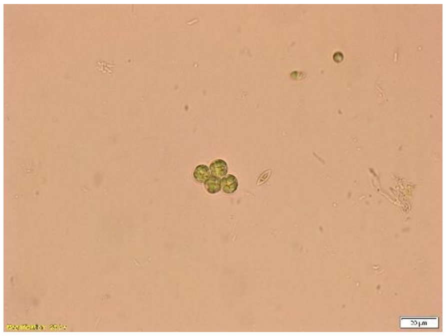


Figure 4: Sphaerocystis Algae (Photo Credit Dr. Terry Baxter)

Figure 6: Euglena.

Figure 7: Coelastrum

Figures 6 and Figure7 show Euglena and Coelastrum microscope pictures.

2.3 Algae Concentration:

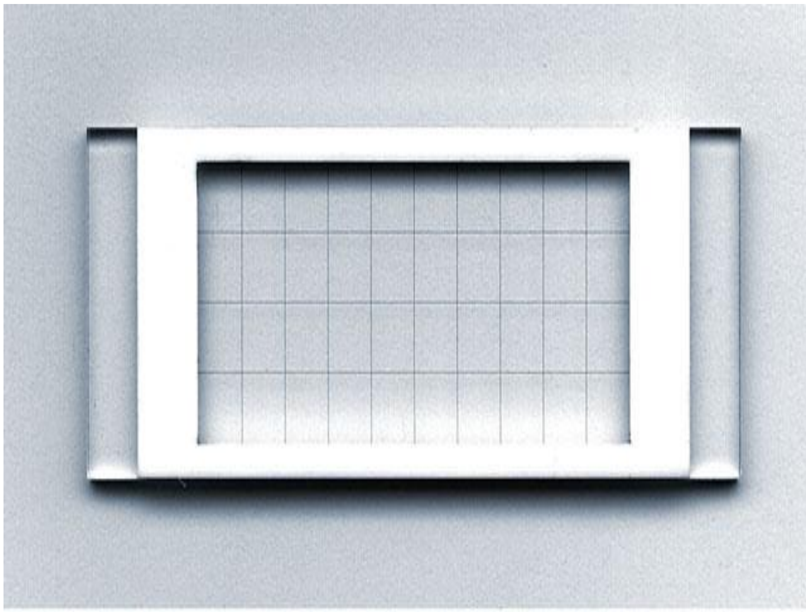


Figure 8: Sedgwick Rafter.

P2BK used the microscope to count algae cells on the Sedgewick Rafter slide. P2BK used the samples to count the algae in order to obtain the algae mass using a protocol to obtain a few calculations. The equation used to calculate the algae cell is:

$$Algae\ Concentration = \frac{\#\ of\ Cells}{ml} = \frac{(\#\ Cells\ Counted)(Total\ \#\ Grids)}{(Total\ Vol.\ H_2O\ Sample)(\#\ Grids\ Observed)} \quad \text{Equation (1)}$$

Equation (1) shows the equation that was used to calculate the algae concentration. Equation (1) value was obtained with the units of number of cells/ mL. The total grids numbers in the Sedgewick Rafter slide was 40 grids. The number of cells that was observed during the algae count was 6 and the total volume of water varied in each time of counting the algae cells.

The average readings for the top and bottom of each pond are as shown in table 2.2 below:

Table 5: Average Reading For each Pond.

Pond ID	Cell Count (cells/ml)		Average (cells/ml)
Pond 1	Top	146.6	206.6
	Bottom	266.6	
Pond 2	Top	133.3	183.30
	Bottom	233.3	
Pond 3	Top	113.3	156.65
	Bottom	200.0	
Pond 4	Top	86.6	126.60
	Bottom	166.6	
Pond 5	Top	80.0	123.30
	Bottom	166.6	

Table 2.2 above shows that pond 1 has the highest count of algae cells. This is because this pond has a lined tar roll that enables algae to consume the algae growth conditions and nutrients without the interference of plants and vegetation, which is the case with ponds 3, 4 and 5 which do not have a lined tar roll. Pond 2 also has a lined tar roll, however it is smaller than pond 1 so algae is more abundant in pond 1.

The team proceeded to test for Total Suspended Solids (TSS) using Standard /method #2540 D in the NAU Environmental labs to obtain mg/L values of solids available in the samples of each pond. Onley top of ponds samples were tested and the TSS results were all assumed to be algae neglecting the percentage of solids.

Table 6: TSS Results.

Sample	TSS(mg/L)	Algae count (cells/mL)
Pond 1	86.6	206.6
Pond 2	96.6	183.30
Pond 3	21.48	156.65
Pond 4	18.32	126.60
Pond 5	50.37	123.30

Table above shows the TSS results of each pond and how they correspond with the algae count results. Ponds 1 and 2 had the highest TSS results due to them having a tar line roll preventing nutrients being consumed by plants. Pond 5 had a high TSS value because there were a lot of vegetation and solids in the sample.

2.4 Theoretical Annual Biomass and Lipid Productivity of the ponds

P2BK decided to calculate the theoretical annual biomass and lipid productivity to compare the obtained values to the values available in the literature. To calculate theoretical annual biomass and lipid productivity of the ponds, P2PK used the following equations:

Annual Biomass Productivity:

$$Volume\ of\ Pond\ (L) * TSS\ of\ pond\ \left(\frac{mg}{L}\right) = Mass\ of\ algae\ in\ pond\ (mg)$$

- Assumptions:
  - ~70% of the TSS value is considered algae.
  - September samples were not obtained peak season. The TSS values will likely be higher during peak (June) as much as 10x higher.

- The algae should be harvested twice/month during peak season.

Pond 1 annual Biomass:

- $Volume\ of\ Pond\ (L) * TSS\ of\ pond\ \left(\frac{mg}{L}\right) = Mass\ of\ algae\ in\ pond\ (mg)$

=12504231 L * 86.6 mg/L = 1,082,866,404.6 mg → 1.08286 tonnes.

- $Pond\ production = \frac{(Mass\ of\ algae\ in\ pond)*(12\ harvests\ in\ a\ year)}{area\ of\ pond\ in\ hectare} =$

$\frac{(1.08286\ tonnes)*(12\ harvests)}{0.8204876\ hectare} = 15.84\ Tonnes/\ ha\ /yr.$

Annual Lipid Productivity:

$$ML_{production(annual)}(L/ha/yr) = \frac{f_L * MB_{productio(anuual)}\ (T/ha/yr)*1000}{P_L\left(\frac{Kg}{L}\right)} \qquad \text{Equation (2)}$$

Where:

$ML_{production(annual)}$ = is the annual average lipid productivity (L/ha/yr).

f_L = is lipid fraction of algae biomass.

P_L = is the density of lipids.

Table 7: Pond Prodcution.

Pond	TSS(mg/L)	Volume of pond(L)	pond-prod(Tonnes/ha/yr)
1	86.6	12504230	15.84
2	96.6	7129910	17.67
3	21.48	10594798	3.93
4	18.32	17317484	3.35
5	50.37	16355136	9.21

Table (2.4) shows that Pond 1 and 2 can produce reasonable amount of algae production. The algae pod production for pond 1 and 2 within the range of an open pond production in Peak seasons. An Open pond can produce 16.6 – 33.1 tonnes algae/hectare/year. These values were taken on September and the pond production rate is expected to be 10 times higher in peak seasons. In addition, pond 1 and 2 will be adequate for harvesting during the peak seasons.

As an estimation, 22.4 tonnes/hectare/year was used.

22.4 tonnes algae/hectare/yr * 4.195 hectares (total area of the ponds) = 93.97 tonnes algae/yr

For the Lipid production, which was based on Chlorella:

93.97 tonnes algae/yr * 0.38 tons lipid/ton algae * 0.9 L lipid/kg lipid *kg/2.2 lb * 2000 lb/ton = 29,215 L lipid/yr

P2BK decided to choose 22.4 tonnes/hectare/year as the value of the ponds taken from the literature. The values obtained for pond production are close to this number, this means that the pond has potential to produce reasonable amounts of algae to be converted to profitable biofuel. However, more tests need to be conducted in the future because the samples were not taken during peak season and if they were there is potential that results will increase.

2.5 Identification of Alternatives:

Because the samples were not taken during peak season, the biomass calculations proved that the ponds had potential but the production rate must be increased. Therefore, P2BK has sought to look for alternative design solutions that can increase the amount of algae produced in the lagoons to benefit future projects on the lagoons.

There are two suggested solutions to increase the growth rate of algae in the wastewater lagoons, the first option is adding chemicals. This method involves adding certain chemicals that help increase algae growth rate along with the presence of important nutrients such as nitrogen, phosphorus and carbon dioxide. Biomass is created by having carbon dioxide combine with the nutrients. Chemicals are introduced to algae to act as metabolic triggers that can control cellular metabolism, this would increase the growth rate of algae. There are many chemicals that can be used, and each type of algae has a chemical enhancer that responds better with it, table 2.5 shows several types of algae and their chemical enhancers.

Table 8: Algae Species and their Enhancing Chemicals.

Algae Species	**Chemicals**
Haematococcus pluvialis	2, 4-Epibrassinolide (EBR)
Chlorella vulgaris	Brassinosteroids (BRs)
Haematococcus pluvialis	Jasmonic acid (JA)
Haematococcus pluvialis	Salicylic acid (SA)
Haematococcus pluvialis	Methyl jsmonate (MJ), gibberellic acid (GA_3)
Microcystis aeruginosa	Polycyclic aromatic hydrocarbons
Chlorella zofingiensis	Pyruvate, citrate, and malic acid
Haematococcus pluvialis	Gibberellic acid (GA_3)
Haematococcus pluvialis	Salicylic acid (SA), methyl jsmonate (MJ)
Schizochytrium sp. HX-308	Ethanol, sodium acetate, malic acid
Chlorella vulgaris	Indomethacin (IM)
Haematococcus pluvialis	Fe, sodium acetate

The second suggested solution is the Algae Raceway Integrated Design (ARID), which is an innovative design of the common open pond method used to grow and harvest algae. This design is suitable for the existing conditions of the lagoons in peach springs because algae growth is effected by several elements such as nutrients, temperature, salinity, sunlight and others. The ARID system addresses some of the main problems facing algae growth in the lagoons in peach springs. It does so by presenting a new and innovative way of fluid mixing in the ponds, which increases the growth rate of algae by producing a uniform concentration field of nutrients and better exposure to sunlight. This new mixture method is also minimizes energy consumption required for flow drive and mixing. Another important issue addressed by the ARID system that is present in the common paddle wheel driven open ponds systems is cold temperature control, which significantly slows down algae growth, especially during the winter season. This issue is resolved through the ARID system by draining the water upon the slope of the raceway bed to a deep reservoir during cold temperatures, this means that the amount of water surface exposed to cold temperatures is as minimal as possible, and this in turn reduces the heat loss suffered by the system.

Figure 9: ARID System.

2.6 Identification of Selected Designs and Final Design

The two alternative solutions aim at increasing algae production rates, however one solution is to be chosen because there are several criteria to choose from, and these criteria determine which the better solution is. The decision matrix below in table 2.6 shows the two alternative solutions and the criteria that were used to compare between them with a scale of 1 to 5 with 1 being worst and 5 being best.

Table 9: Decision Matrix.

Alternative solution	Criteria	Scale
Adding chemicals	Cost Efficient	4
	Easiness of implementation	5
	Increase Algae growth	4
ARID	Cost Efficient	3
	Easiness of implementation	3
	Increase Algae growth	4

The table above shows a simple decision matrix that compares between the two alternative solutions suggested using three criteria which are Cost efficiency, easiness of implementation and increase of algae growth. The first alternative solution, which is adding chemicals received a score of 13 points, with 4 points in the cost efficiency criteria, this was the case because the chemicals are relatively inexpensive and there is no need to change the profile of the pond in any shape or form. Some examples of chemical costs are Ethanolamine: 1000$/kg, Propyl gallate: 367$/kg and Gibberellic Acid: 3330$/kg. These costs might vary depending on the amount of chemicals needed. This alternative solution also received 5 points in the easiness of implementation criteria because chemicals require the simple process of dosing, which can be done by one person pouring the chemicals into the ponds over a certain period of time, there is no need to install any machinery of any kind. Finally, this alternative solution received 4 points in the increasing algae growth criteria because it is allows the abundant types of algae in the pond to receive chemicals that are the best to increase their growth rate.

The second alternative solution, the ARID system received a score of 10 points, with 3 points for cost efficiency, this was the case because the system requires changing the ponds' shapes to accommodate the design of the ARID system and this will cost a significant amount of money. Furthermore, this alternative solution has received 3 points in the easiness of implementation criteria because, as mentioned previously, it needs changing the ponds' shapes, which requires a lot of digging and filling. Finally, this alternative solution received 4 points in the increasing algae growth criteria because the system is designed to provide a unique way to mix algae that overcomes some of the main problems facing algae growth such as cold weather.

From the previous information we can infer that the alternative solution that suits the conditions of the Hualapai waste lagoons the most is the chemicals adding solution, because it had a higher score on the decision matrix due to its excellent cost efficiency, easiness of implementation and satisfying the needed algae growth for future projects.

3.0 Recommendations

The company recommends some procedures to be made for future projects involving the Hualapai waste lagoons to increase algae production. These recommendations include Additional sampling in peak season using a sampling plan, increasing algae production rates by adding nutrients along with mixing.

3.1 Additional sampling in peak season

The company recommends that a sampling plan should be implemented, with sampling occur once each month on the months of (October-January) which is not the peak season and sampling should occur twice each month on the months of (February-September) which is the peak season, especially from (April-June). This is because algae settles near the surface of the ponds during peak season, making it easier to take samples and harvest the algae.

The company also recommends that algae should be preserved under special light in labs, sample bottles should be left open to allow air to enter and contact the algae and the samples should be tested during the first week after they were taken to insure more accurate results. In addition, further identification of algae species must occur to have a better idea on what other types of algae are available and what are their amounts in the lagoons, and further TSS concentrations of the ponds must be determined, especially on samples taken during peak season because of the potential of having biomass results that are as much as 10 times higher than the ones mentioned in this report. Finally, additional tests should occur in the algae samples such as a lipid test to know how much lipid is available in the ponds for biofuel production.

3.2 Mixing nutrients and chemicals

The company recommends that mixing should occur in the ponds because it provides greater contact between chemicals and nutrients, and the algae which increases algae growth. Mixing can occur using paddlewheels, there are two types suggested by our company and they are turbine powered paddlewheels Figure 4.1 and mobile paddlewheels Figure 4.2. The paddlewheels cost around 200-600 $/paddlewheel.

Figure 10: Turbine Powered Paddlewheel.

Figure 11: Mobile Paddlewheel.

4.0 Summary of Project Costs:

Table 10: Staffing Hours.

Task	SENG,hr			ENG,hr			Lab Technician,hr		
	Khaled	Abdullah	Saleh	Khaled	Abdullah	Saleh	Khaled	Abdullah	Saleh
1.0 Algae Characterization	12	15	12	23	25	24	10	10	8
2.0 Alternative Solutions	10	11	11	40	35	42	5	10	11
3.0 Project Management	15	10	14	31	33	27	8	5	4
Total for each personnel	Khaled 154 Hours			Abdullah 154 Hours			Saleh 153 Hours		

The table above shows the hours of each member of the team and what the roles of professionals for this project were. The total hours for this project were 461 hrs, Khaled Jaber worked for 154 hrs, Abdullah Zakareia worked for 154 hrs and Saleh Ahmad worked for 153 hours.

Table 11: Original Cost.

Item	Classification	Hours	Rate $/hr	Cost
1.0 Personnel	SENG	90	130	$11,700
	ENG	200	71	$14,200
	LAB	160	50	$8,000
	Total Personnel	450		**$33,900**
2.0 Analytical supplies	Glassware, PPE, filters and microscope			**$1,000**
3.0 Travel	2 trips,226 miles/trip	$0.4/mile		$181
	2 days vehicle rental $55/day			$110
	3 persons per diem, $34/day			$204
	Total Travel			**$495**
Project Total				**$35,395**

Table 12: Actual Cost.

Item	Classification	Hours	Rate $/hr	Cost
1.0 Personnel	SENG	110	130	$14,300
	ENG	280	71	$19,880
	LAB	71	50	$3,550
	Total Personnel	461		**$37,730**
2.0 Analytical supplies	Glassware, PPE, filters and microscope			**$1,000**
3.0 Travel	2 trips,226 miles/trip	$0.4/mile		$181
	2 days vehicle rental $55/day			$110
	Total Travel			**$495**
Project Total				**$39,552**

The two tables above show the project costs, the first table is the predicted cost of the project taken from the proposal and the second table is the actual project costs. The actual cost is higher by approximately $4,000 due to the increased working hours for the team members Senior Engineer and Engineer. However, the lab technician's hours are less than predicted due to the amount spent in the lab being less than predicted.

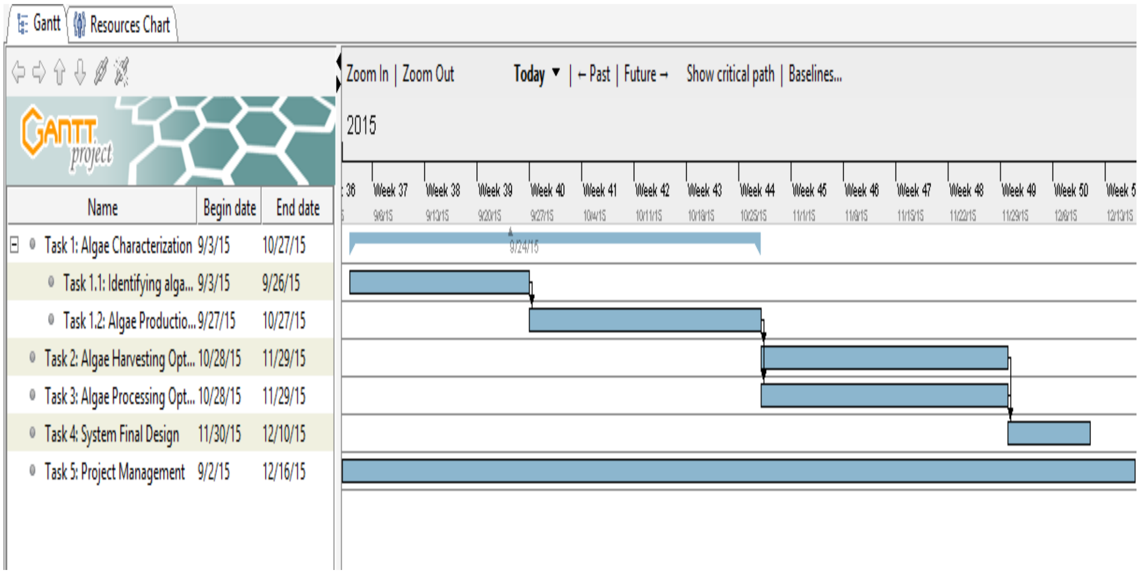


Figure 4.3: Original Gantt chart.

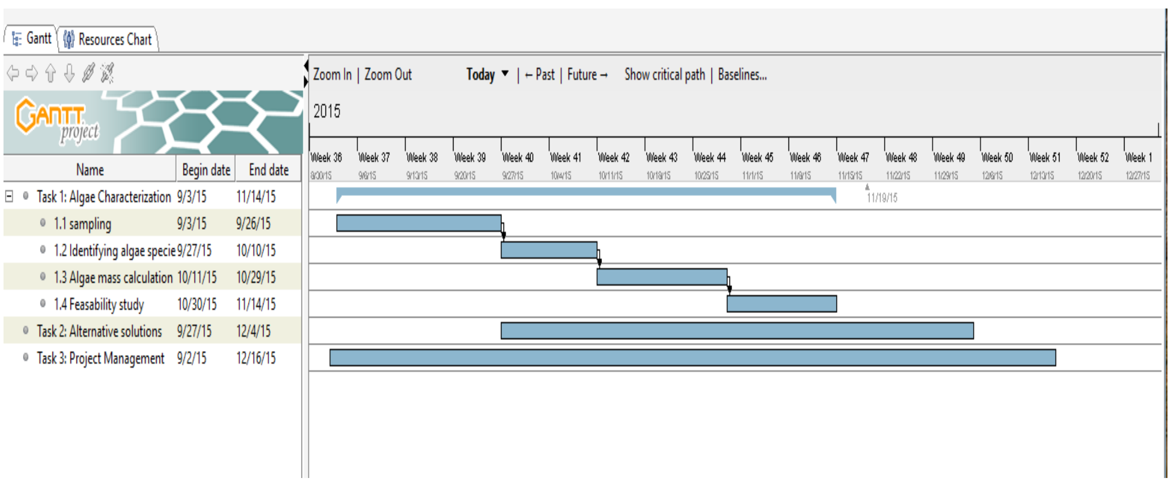
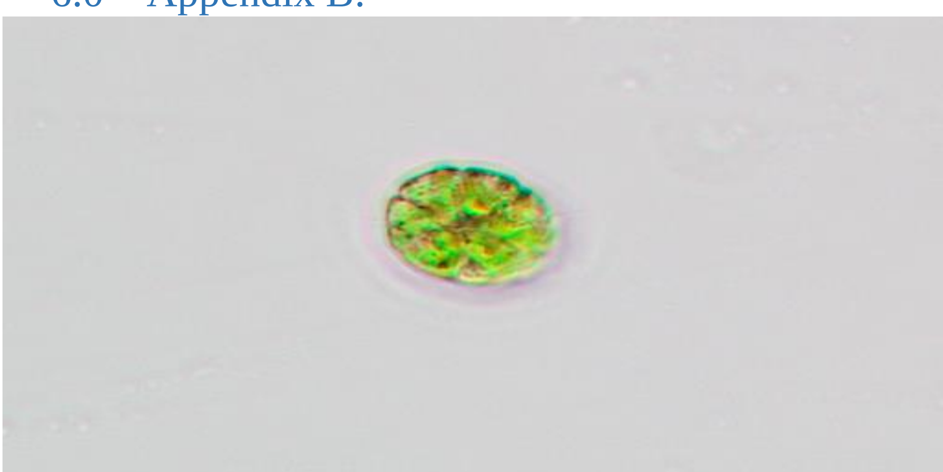


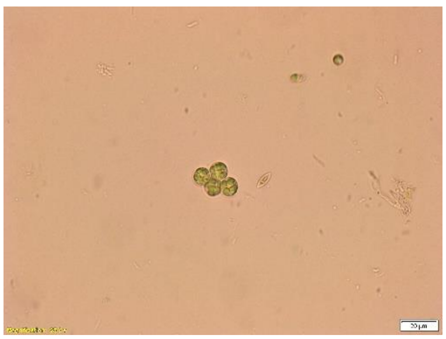
Figure 4.4: Current Gantt chart.

The two Gantt charts above show the project schedule as it was predicted in the proposal on the company's website and the second Gantt chart shows the current schedule. The tasks in the two Gantt charts are different because the project has started as a feasibility study but turned into a research project due to the lack of information needed to make a profound decision if the lagoons have enough algae to produce profitable amounts of Biofuel. Instead, the project took a path towards providing more information on the lagoons and stating that the lagoons had potential for biofuel production, but it needs more research and testing for future projects.

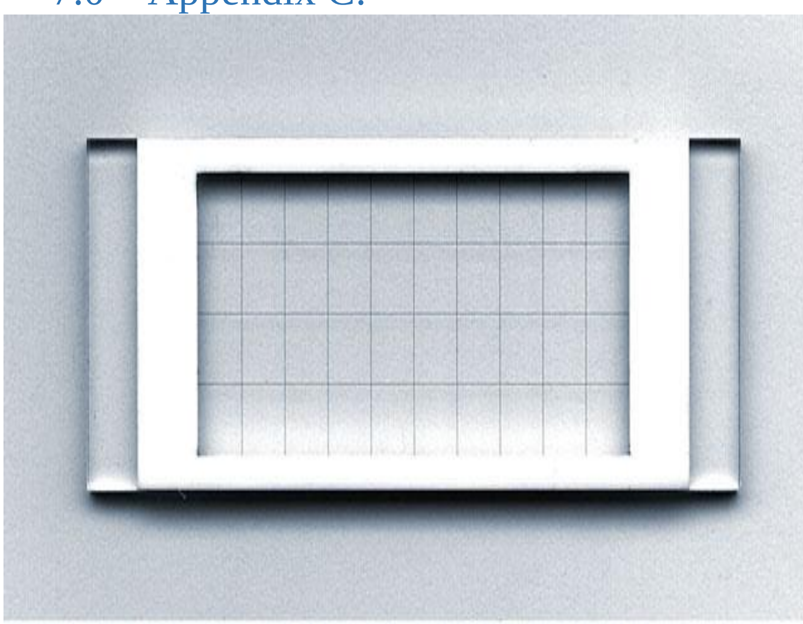
5.0 Appendix A:

6.0 Appendix B:

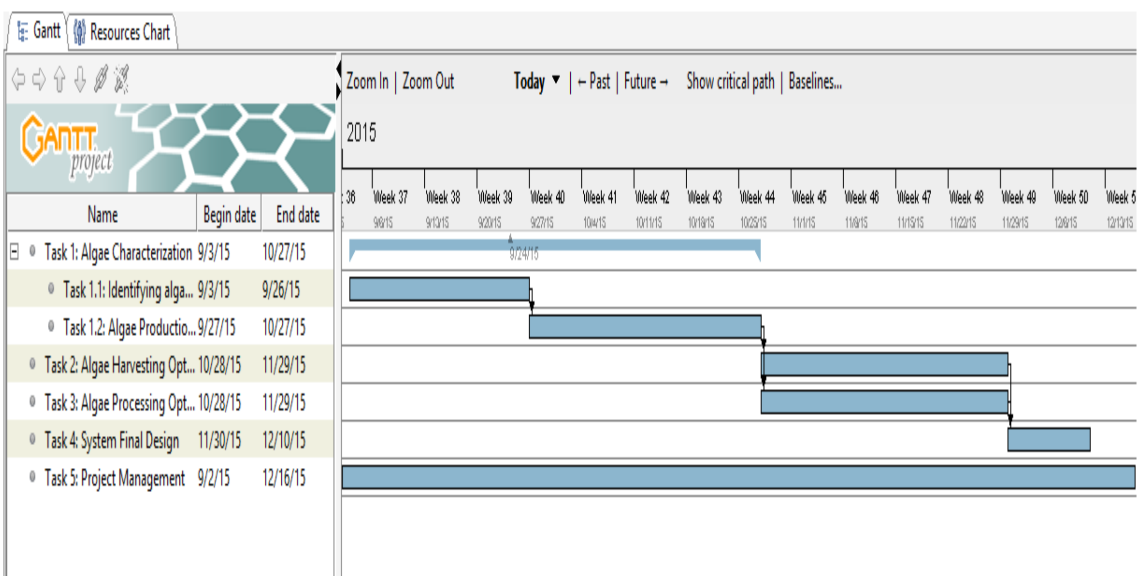


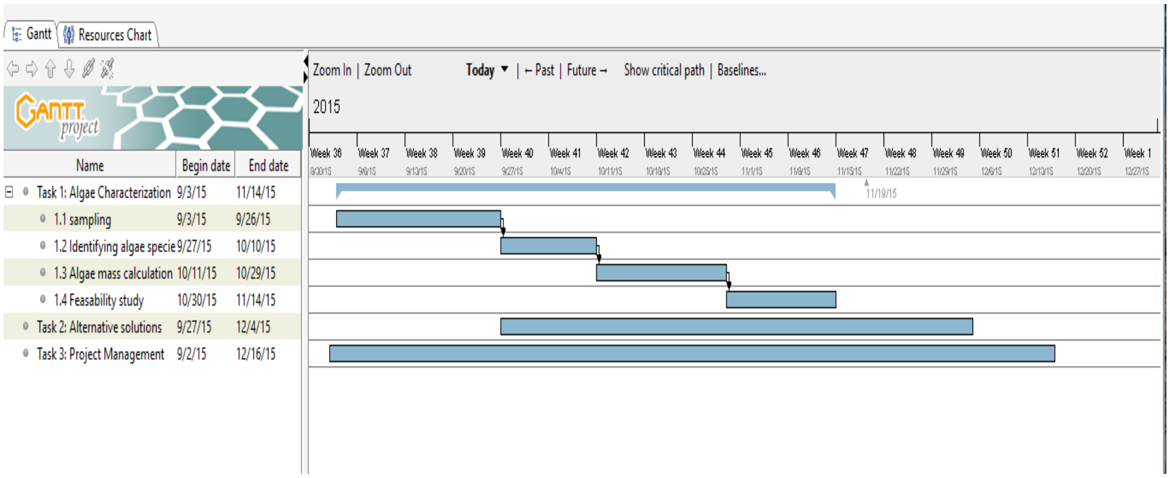


7.0 Appendix C:




TA-747H, 2HP, 8 impellers, 143 RPM, 5 ~ 6 ampere(220V)


Gantt
Resources Chart
GANTT project
Zoom In | Zoom Out
Today ▼ | ← Past | Future → Show critical path | Baselines...
2015
Name
Begin date
End date
Task 1: Algae Characterization 9/3/15 10/27/15
Task 1.1: Identifying alga... 9/3/15 9/26/15
Task 1.2: Algae Productio... 9/27/15 10/27/15
Task 2: Algae Harvesting Opt... 10/28/15 11/29/15
Task 3: Algae Processing Opt... 10/28/15 11/29/15
Task 4: System Final Design 11/30/15 12/10/15
Task 5: Project Management 9/2/15 12/16/15
Week 37 Week 38 Week 39 Week 40 Week 41 Week 42 Week 43 Week 44 Week 45 Week 46 Week 47 Week 48 Week 49 Week 50


Gantt
Resources Chart
Zoom In | Zoom Out
Today | ← Past | Future → Show critical path | Baselines...
2015
Name
Begin date
End date
Task 1: Algae Characterization 9/3/15 11/14/15
1.1 sampling 9/3/15 9/26/15
1.2 Identifying algae specie 9/27/15 10/10/15
1.3 Algae mass calculation 10/11/15 10/29/15
1.4 Feasability study 10/30/15 11/14/15
Task 2: Alternative solutions 9/27/15 12/4/15
Task 3: Project Management 9/2/15 12/16/15
Week 36 Week 37 Week 38 Week 39 Week 40 Week 41 Week 42 Week 43 Week 44 Week 45 Week 46 Week 47 Week 48 Week 49 Week 50 Week 51 Week 52 Week 1
11/19/15

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