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Modeling Cost Structure for Assessment Production Cost of Algal - Biofue

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Abstract—Algae-based fuel are considered a promising sources of clean energy, and because it has many advantages over traditional biofuel, research and business ventures have driven into developing and producing Algal-biofuel. But its production stages create a cost structure that it is not competitive with traditional fuels. Therefore, cost becomes the main obstacle in commercial production purpose. However, the present research which aims at using cost structure model, and designed MS-Dose program, to investigate the a mount of production cost and determined the parameter had great effect on it, second to measured the amount of contribution rate of algae in process the pollution by capturing Co2 from air . The result generated from the model shows that the production cost of biomass is between $0.137 /kg for 100 ha and $0.132 /kg for 500 ha which was less than cost of other studies, while gallon costs between $3.4 - 3.5, more than traditional sources of oil about $1 ,which regarded as a rate of contribution of algal in capturing CO2 from air.

Keywords**—**Cost Structure Model, Operation Costs(Production Cost), Capital Costs, Algae.

I. INTRODUCTION

THE problem of Petroleum shortages and its climate implications have driven research and business ventures into algae-based fuels [1]. Although efforts to produce renewable energy on an industrial scale have been started in many alternative renewable energy sources like solar power, wind power, corn biofuel….etc, but producing biofuel from algae, is one of the most promising sources according to the historical revolution in biofuels industry that characterized Algae as the third revolution[2]. The promise of sustainable energy production from algae has generated tremendous interest in recent years[3]. Therefore algae was picked in addition to the nuclear and wind power as the most likely alternative energy sources of the future [4] , a number of researches working on studying natural habits of algae and their characteristics, because algal-biofuel could be produced from Macroalgae or Microalgae which have taken the biggest share in the researches[5], some classified them to four important categories[6], and the algae- strains from 3000 to 100000 kind. But the most important studies are focused on identifying strains exhibiting high oil- content, and which is suitable for commercial purpose [7] , [8], [9] , [10], [11], [12], [13], [14] ,[15], [16], [17], [18] , [19], [20].

They indicated the oil content from 7% – to 75 % dw .Therefore algae have been cultured for their high-value oil Some researches indicate that the quality of oil derived from algae like diatoms which geologists claim it was the source of much of the crude oil has much better oil products than oil produced from plants like Soybean. Moreover its ability for commercial [1]productions is much higher [21]. Algae like any commodity has to go through many stages in order to converted oil. It has specifics condition that makes it more complex, because algal-biofuel represent a complicated intersection of industries. Therefore, we mapped the production pathways as shown in Table1.

TABLE I
STAGES OF ALGAE PRODUCTION

NO	STAGE	THE OPTIONS OF PRODUCTION IN EACH STAGE			
1	Cultivation*	Open ponds	Photo reactors	Hybrid system	Fermentation
2	Harvesting	Flocculation	Centrifuge	Flotation	Sedimentation & Filtration
3	Extraction	Expeller Press	Hexane solvent	-	-
4	Conversion to biofuel	Trasesterification		-	-

In order to identify the stages of the production system that's helpful in determining the various components of total production costs. The most suitable option available for mass-production is open pond, which is the sample of this research. But commercial production face many obstacles. One of them is the costs. The earlier basic researches and other’s, laid the foundations for the applied research in Algae biofuel production, but the strong initiative came after the energy crisis of the early 1970s. Since then researches focused on studying algae from the point of view of chemistry, engineering, biology,..and other sciences fields.

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A few studies in early times were concerned more about economic analysis, to calculates cost from the view of economic field like studies of Fisher [22,23],Oswald [24], Benemann [25] and others. We argue that none of the previous studies had investigated the element costs of Algal-biofuel production from the accounting view. Therefore, this research fills this gap by applying cost accounting terminology. The most complementary and complex approach to evaluated the cost of a particular biofuel algal produced is to modeling the entire process to determine the approximate production costs and to assess which factors are the most important and effect the final production cost. So, we will benefit from this previous researches in the formulation hypotheses, modeling cost structure, determining the parameters of the model, setting up the equation, designing the program to calculate the production and capital cost.

II. DEVELOPING OF THE COST MODEL

The more complex approach is to modeling the costs of whole process. The previous component of an algal production process and input have to be factored in the model. Although the model include all of the factors, but some were not, like the costs of drying, packaging, marketing and capital cost of these stages because of lack of data. The modeling keeps the focus on the ultimate goal which is the final cost of production. For that, all steps and important parts, with equations used in calculating the final cost are listed in Figuer.1.

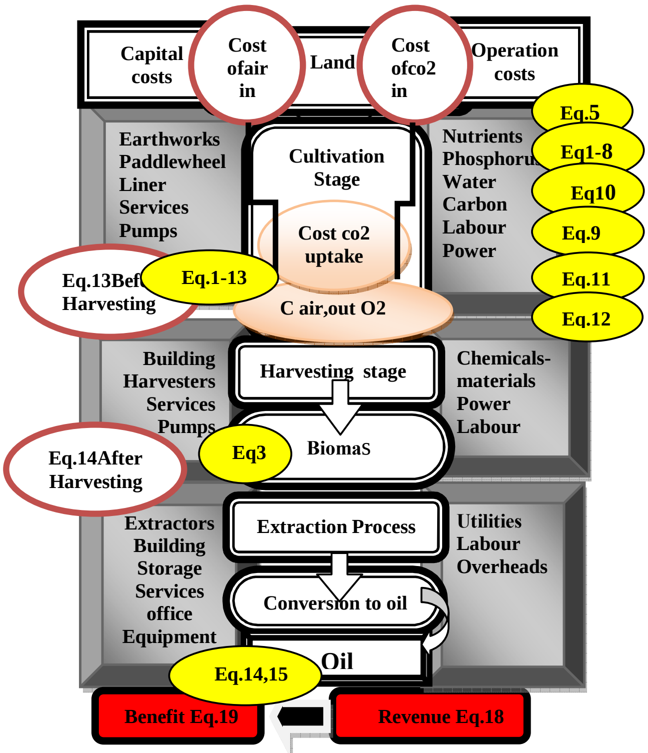

Fig. 1 Schematic diagram shows several component of model for algae-biofuel production

The main elements concern in producing biofuel from algae are the cost and availability of resources [26], [27]. The cost of installs and maintenance the system [28] , capital and operation costs, they must be presented here as basic items in the restructured cost modeling. A few studies provided cost structure, and variety in structured elements cost. One famous was Benemann cost structure [29]. But, this structure offered from the viewpoint of economists So, we will restructure the elements cost according to the accounting terminology by using full cost statement as in Table.2 in order to add some elements not take in consideration and to distinguish between direct cost that represent variable cost which was the important cost elements in production and the determined marginal profits. The model assumption noted in Table. 3 as a key parameters. The important chemical, biological and engineering information to formulate these assumption were taken in consideration , depended upon the results reached by previous studies [30] , [31] .

TABLE II
STATEMENT OF THE FULL COST STRUCTURE

COST STRUCTURE	
OPERATION COSTS (PRODUCTION COST)	CAPITAL COSTS:
Direct Cost: 1- Raw material (Algae spices) 2- Secondary materials Chemical material: - Co2 (commercial or capture from air) - Na2Co3 - NH3 - Urea - H3Po4 - FeSo4 Water: - Make up ,Fresh - Make up, Brackish 3-Direct labour: -Operators -Supervisors 4-Direct overhead: -Electricity -Fuel, gas, or oil -General supplies 5-Indirect overhead: -Depreciation -Maintenance -Insurance -Others indirect cost **Final cost estimation** 1-Productioncost before harvesting 2-Production cost after harvesting	1- Land cost 2- Cost of preparation land and equipments 3-Algae Growth area(ponds) -Number of ponds - Total pond area (length, width, depth). - Pond operating depth - Single pond area - Single pond volume - Number of times ponds setup per year - Levees - Lining(ashaltic concrete - Channel divides - Pump chambers - pumps&Transfer stations - Mixing system (Paddle Wheels) - Carbonation System - Water Storage 4- Harvesting tanks :Sewage type clarifiers 5- Algae removal equipment Building, Offsite 6- Engineering constructions Circulation equipment 7- Cooling facilities 8- Pre harvest equipments 9-Centralheating equipments 10- Co2 supply system 11- Contingencancies 12- Working capital

TABLE III
PARAMETERS AND ASSUMPTIONS OF COST MODELING

PARAMETER	ASSUMPTION
Carbon credits	$2 – 40 / ton
By product values	$30 – 300 / ton
Biomass production rate	25 – 200 g / m2 / day
Oil content	3% to >60%
Separations	0.02 - $20 / gal
Land area	=> 100 ,200,300,400,500 ha
Cost of hectare of land	1000$
Cultural method	Open pond depend on, length, width, depth (0.2-0.3m)
Capital cost	site preparation, culture system, engineering fee, contingency land
Harvesting efficiency	=<90%
Proportion of pond harvested	=<50%
Proportion of medium recycled	=<90%
Rate of evaporation	=<0.03m
Total growth days	330 -360 day
Volumetric productivity	0.078-0.098g/l.d
Arial productivity	Depending on volumetric productivity, depth
Annual extra volume culture media needed	5978.8 l/d
Nitride required to remaining culture media in the pond	=<448 kg/d
Nitride required to add to harvested culture media	=<430 kg/d
Nitride required to reach the concentration annually	=<852 kg/d
Nitride cost	1 $/kg
Phosphorus required to reach the concentration annually	=<34 kg/d
Phosphorus cost	1.5 $/kg
CO2 cost	0.068 $/l
CO2 required	0.35-0.45 l/d
Fresh water cost	0.05 $/m3
Labour cost	$/hectare. y
Power cost	0.15 $/kw.hr
Power usage	65 kw /ha.d
Price of un harvested algae	>5.9 $/kg
Price after harvesting	7.35-14.17 (0.1-0.52$/m3 (Total days of harvesting 140)
harvesting methods.	Flotation &Flocculants
Insurance ,Depreciation ,Maintenance, Other costs	(TCAP×2%) ,(TCAP×10%) , (TCAP×3%) ,=TCAP×1%
Fcl=dry mass microalgae lipid content fraction usable	0.5-0.72
Pcl=density of lipids useable for conversion to biodiesel	0.88kg/l

These assumptions were made concerning:

(1) Production plant and prescription of culturing algae and harvesting cost parameters, :many technologies culturing methods are available, but the most famous one used for commercial purpose is open pond raceways (Benemann,J,2009). The design of factory of algae from open pond has specific prescriptions for each one (length 530, depth 0.2,width 12),on total Arial land used as a variable parameter are (100, 200, 300, 400, 500) hectare, with total number pond (157,314,471,628,785). Because algae can grow any where, we may choice sites with low cost and set up this pond. This mean that agricultural land can be purchase for low cost. A cost of $1000 /ha was used as a base case for model, which assumed a large algal production, taking in consideration that these lands were assumed to be flat terrain.

A slope of more than 1% requires earth workers and thus significantly increases cost. Site selection should consider climate conditions, from temperature to sun light, providing optimal growth condition for longest possible period. Also, harvesting is one of the major cost factors in producing biofuel from algae. Harvesting from open raceways is usually undertaken as a two step procedure in which the algae are first concentrated to a suspension of roughly 1% solids, followed by an energy intensive concentration to 15-25% solids , Since there are many methods, the flocculation is used in this model, because it is the least expensive for achieving the first concentration step. The cost of the flocculants (or the concentration of flocculants required) is very important. It represents a very significant cost factor. If the cells could be harvested without flocculation as, for example, by filtration significant cost saving would be achieved.

All cost expenses, purchasing and installs equipment, sit preparation for culturing and harvesting are considered capital cost and calculated by the equation below.

$$TCAC=TPA\times(C.SIP+C.CLS+ENG.F+COG+ C.LAND) \quad (1)$$

Where TCAC=Total capital cost, TPA=Total Pond Area, C.SIP=Cost of Site preparation, C.CLS=Cost of Culture system , ENG.F = Engineering fee, COG=Contingency, C.LAND = Cost of Land

(2) Operation items: this item is divided into tow categories (direct and indirect costs). Direct cost, the main cost items listed her, is algae spices as raw material with percentage of oil content varies between (5% and 60%). The suitable percentage choice is 30%. We should explain here that any economics analysis did not take the cost of it in consideration. The other, items are the secondary raw material used in culturing algae, like CO2, water, nitrite, phosphorus, Nacl…etc. The quantity and the cost of each one was determined according to manufacture conditions, considering that CO2 and water costs must be zero because it assumed free goods. Therefore, we investigate her if they were free otherwise have a significant effect on final cost. even the nutrient item should be free, like using the wastewater, we can see if there is small or big impact on the final product's cost, by calculating the cost of each item in a separate equation as below:

Total annual cost for CO2 :

$$TC_{ph} = CO_2C \times CN_{ph} \times (TPV\times1000) \times (1-(PDW) \quad (2)$$

Where CO_2C= Co2 cost, CN = Co2 required for different ph, TPV= Total Pond Area, PDW= Proportion of down time

Total cost for nutrients :

$$AEV=TPV\times PPH\times TGD\times(1-HE) \quad (3)$$

$$NARC=NUC\times PPH\times TGD(TPV\times1000) \quad (4)$$

$$NAHC=NUC\times TGD\times PMR\times(TPV\times1000)\times(1-PPH) \quad (5)$$

$$NPE = AEV \times NCM \quad (6)$$

$$NGN = NARC + NAHC + NPE/1000 \quad (7)$$

Where AEV= The annual extra volume of culture media to replete the amount of lost, TPV= Total Pond Area, PPH= Proportion of pond harvesting, , TGD= Total growth days, HE= Harvesting efficiency, NARC= The nutrients added to make up for it take up by cells, NUC= Used nitride from culture media, NAHC= The amount of nutrients added to the medium, PMR= Proportion of medium recycled, NPE=The amount of nutrients required for making up the extra culture media, NCM =NaNo3 concentration medium, NGN= The amount of nutrients added per year.

Annual cost for total fresh water added :

$$\text{T.FW.C}=\text{TPA}\times\text{ARD}\times\text{AR} \qquad (8)$$

Where T.FW.C= Annual cost for total fresh water added , TPA= Total Pond Area, ARD=Average rainy days, AR= Average rain

The cost of Labour required for pond and equipment maintenance, monitoring of the cultures, harvesting, extraction and further processing. Any improvements in the design of the process and automating the operations of the plant which decrease the labour requirement, without unreasonably increasing in capital costs need to be considered carefully as a possible means of reducing production costs.

$$\text{TLC}=\text{LCS}+\text{LCST}+\text{LCTD}+\text{LCTS} \qquad (9)$$

Where TLC= Labour cost, LCS= Labour cost supervisor, LCST= Labour cost senior technician LCTD= Labour cost technician-day term, LCTS= Labour cost technician-shift term.

Indirect cost, like cost of power, insurance, depreciation, maintenance…etc calculated by the following equation

$$\text{POC} = 24\times \text{POC} \times \text{POU} \times \text{TGD} \times \text{TPA} \times (1-\text{PDW}) \qquad (10)$$

Where APOC= Annual power (Electricity) cost, POC= Power cost, POU= Power usage, TGD= Total growth days TPA= Total Pond Area , PDW= Proportion of down time

$$\text{Insurance} = \text{TCAC} \times 2\% \qquad (11)$$
$$\text{Depreciation} = \text{TCAC} \times 10\% \qquad (12)$$
$$\text{Maintenance}= \text{TCAC}\times 3\% \qquad (13)$$
$$\text{Others} = \text{TCAC} \times 1\% \qquad (14)$$

Where TCAC= Total capital cost

(3) Productivity of the system and manufacture condition :in addition to all of the factors mentioned above, the most important factor is productivity, assuming that currently achievable productivity is about 50% with oil lipid about 30%.To produce algae-biomass or biofuel we must have a good understanding of those factors that limit algae growth, because there is no use of spending many expenses without gaining high rate of productivity. therefore the efficiency depends on many conditions like the period of operation, the period of maintenance, which must be specified since it was unreasonable to be occurred in a rainy season. The rate of evaporation should be determined as well.

Also productivity is effected by harvesting efficiency, proportion of pond harvested, medium recycled, down time…etc. All these factors determine the volumetric, areal or annual productivity. In this work we assume that the harvesting efficiency is 90% to get a highest percentage from biomass cakes. To calculate productivity there are two equations, one for Arial productivity and the other for annual as below:

$$\text{AR.P}=\text{VP}\times (\text{PD}\times 1000) \qquad (15)$$

Where AR.P= Arial productivity at various levels of (Ph), VP= Volumetric productivity, PD= Pond depth

$$\text{AN.P}=\text{VP}\times\text{TGD}\times(\text{TPV}\times 1000)\times(1-\text{PDW})\times\text{PPH}\times\text{HE}/1000000 \qquad (16)$$
$$(\text{BP})=((\,(\text{fcl}\times\text{Pa})/\rho\text{cl})\times\text{length}\times\text{width}\times\text{No of ponds})/3.75/45 \qquad (17)$$

Where Rate of production lipids =BP , fcl=dry mass microalgae lipid fraction, Pa=Arial productivity (kg/m2.y) , ρcl=lipid density(kg/l) in order to reach the goal of producing microalgae biofuels with competitive cost and price similar to recent or likely future oil price,
The equations below measure the price that match the cost or more to gain profit .

$$\text{Revenue (R)}= (\text{oil ppb} \times \text{price})/\text{AVP} \qquad (18)$$

Where Oil ppb = oil yield : AVP = annual productivity

$$\text{Profit}= \text{Revenue} - \text{operation Cost} \qquad (19).$$

Also care was taken to update older data to current time with 2% annual inflation rate.

III. Experimental Procedure And Analysis Of Results

By using MS-DOS program designed to process the input data noted in Tabel.4, and to calculate the value of the parameters and solving the equations of the cost, we tested two most important parameters, which were land area in deferent sizes (100, 200, 300,400,500ha) and productivity, in addition to other parameters to measure which one had the greatest effects on the total production cost.

The results we obtained as shown in Table 5. indicate important points which were:

1- The production cost of gallon was between $ 3.4 - 3.5, and the cost of barrel between ($143.88-$151.51), which was less than the cost calculated by Harmelen [32], and this was a fair cost comparison with the cost of gallon of crud oil, where the difference ($1) between the cost of a gallon of crude oil 2.5 and the Algae - biofuel 3.5 represent the return contribution to prevent environment from pollution.

2- The total cost was less sensitive to culture area but it is much sensitive to the productivity as shown in Figure 2, even the cultural area had different effect on the production cost before and after harvesting process, the cost after harvesting was much higher than the cost before harvesting as shown in Figure 3. Also the effect of cultural area on operations, capital, and total costs had the same effect as shown in Figures 4, and 5, However, the total cost can be reduced by improving the harvesting efficiency and increasing the productivity of algae spices oil content.

3- The production cost components like water and CO_2 costs are of high major significance as shown in Figure 7, Contribution of each items to total operation cost were, for, $CO_2$14.5%, power 23%, labour 5.6%, water 1.7%, nitrite 1.68%, phosphors 0.1%, contrary to what was supposed for CO_2 and water to be zero cost (costless), as long as most of the medium can be recycled after harvesting.

The cost was the most sensitive due to the increase of labour required for pond and equipment maintenance, monitoring of the cultures, harvesting, extraction and further processing. Any improvements in the design of the process and automating the operations of the plant would decrease the labour requirement, where as nutrient as little impact. This result came up identical with the work of [33]. Finally Figure 6 showed that the revenue increased to 400 ha and then jumped sharply to 500 ha of cultural area, which means that good benefit was confirmed at 500 ha of area.

TABLE IV
INPUT DATA

	ITEMS	ABBREV	VALUE	UNITS
1	Cost of Site preparation	C.SIP	16000	$/ha
2	Cost of Culture system	C.CLS	240000	$/ha
3	Engineering fee	EF	38400	$/ha
4	Contingency	COG	12800	$/ha
5	Cost of Land	C.LAND	1000	$/ha
6	Land / Area	LAND/ AREAL	100,200,300,400,500	ha
7	Total growth days	TGD	330	day
8	Proportion of down time	PDW	15%	%
9	Proportion of pond harvesting	PPH	50%	%
10	Cost of nitride	ANC	1	$/kg
11	Cost of phosphors	APC	1.5	$/kg
12	Harvesting efficiency	HE	90%	%
13	Pond depth	PD	0.2	M
14	Pond length	PL	530	M
15	Pond width	PW	12	M
16	No of ponds	No.P	157,314,471,628,785	-
17	Used nitride from culture media	NUC	0.0075	g/l
18	Proportion of medium recycled	PMR	90%	%
19	Algae doubling time	td	< 2	day
20	NaNo3 concentration in medium	NCM	0.075	g/l
21	Used phosphors from culture media	PUC	0.0003	g/l
22	NaH2PO4.1 H2O concentration	PCM	0.005	g/l
23	Volumetric productivity	VP	0.078	g/l.d
24	Co2 cost	CO_2 C	0.068	$/l
25	Co2 required for different ph	CN ph	0.35	l/d
26	Fresh water cost	FWC	0.05	$/m^3
27	Average days of evaporation	ADE	330	D
28	Rate of evaporation	RE	0.03	M
29	Average rainy days	ARD	25	D
30	Average rain	AR	0.1	m.d^{-1}
31	Labour cost supervisor	LCS	2058.33	$/ha.y
32	Labour cost senior technician	LCST	2816.66	$/ha.y
33	Labour cost technician-day term	LCTD	6933.33	$/ha.y
34	Labour cost technician-shift term	LCTS	3900	$/ha.y
35	Power cost	POC	0.15	$/ha.y
36	Power usage	POU	65	$/kw.hr
37	Harvesting system cost annually	AHC	(.35)	$
38	Oil lipid	oilp	(30%)	$
39	Price /barrel of Oil	price	150	$

Note: Barrel=42 gallon (according to US measurement) adoption of digitaldutch **/info@digitaldutch.com**

TABLE V
OUTPUT DATA OF MICROALGAE COST MODELING BIOFUEL PROCESS

AREA(HA) PARAMETERS	100	200	300	400	500
Capital cost ($)	3.077 E+07	6.154877 E+07	9.232316 E+07	1.230975 E+08	1.538719 E+8
Annual productivity (Ton/y)	1966.196	3932.392	5898.587	7864.783	9830.979
Total cost ($)	3.02E+07	6.1E+07	9.08E+07	1.2E+08	1.5E+08
Operation cost ($)	2.785418 E+5	5.570837 E+05	8.356255 E+05	1.114167 E+06	1.392709 E+6
Biomass cost ($ /ton)=operation cost /Annual productivity	137	139	140	139	132
Biomass cost ($ /kg)=Operation cost / Annual productivity	0.137	0.139	0.14	0.139	0.13
Cost before harvesting($/kg	4.06	2.031767	1.354511	1.015883	0.8127068
Cost after harvesting($/kg	6.59	3.297375	2.19825	1.648687	1.31895
Biodiesel productivity (gallon/y) oil yield = 30	202930	405861	608791	811722	1014563
Biodiesel productivity (barrel/y) oil yield=30	4509	9019	13528.7	18038	22547
Biodiesel productivity (barrel/ton)	2.3	2.2	2.3	2.3	2.3
Barrel cost ($/ barrel) add 9% of biomass cost as extraction process cost	150	151.51	152.6	151.51	143.88
Gross annual revenue ($/ton)	344	344	344	344	344
Profit ($/ton) (Revenue- Biomass cost)	207	205	204	205	312
Profit (Revenue - Barrel cost)	194	192.49	191.6	192.49	200.12
Cost of gallon($	3.57	3.6	3.62	3.6	3.42

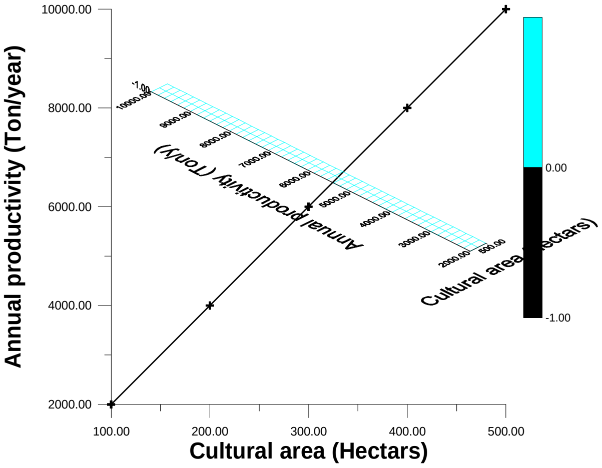

Fig. 2 Effect of cultural area on annual productivity

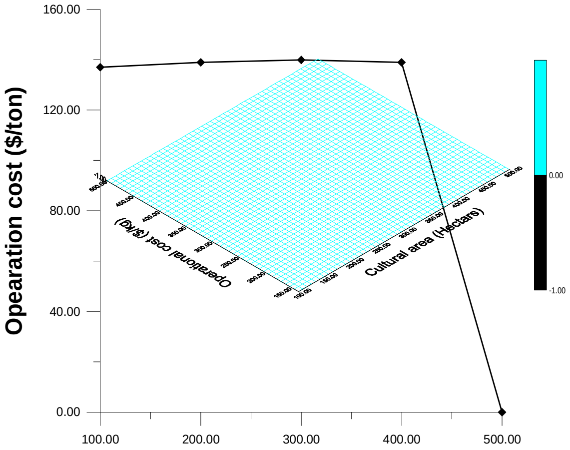

Fig. 5 Effect of cultural area on the unit of . operation cost

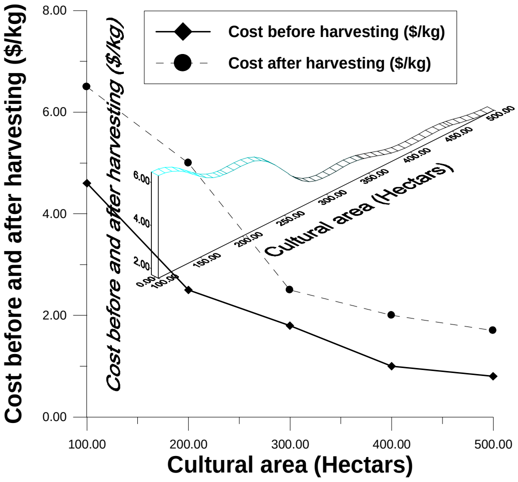

Fig. 3 Effect of cultural area on cost before and after harvesting process

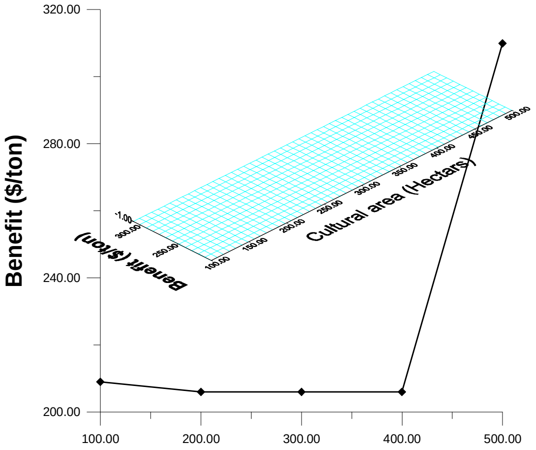

Fig. 6 Effect of cultural area on benefit

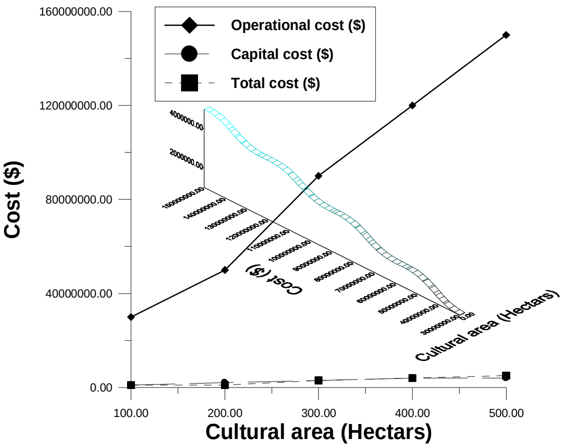

Fig. 4 Effect of cultural area on operation , capital and total costs

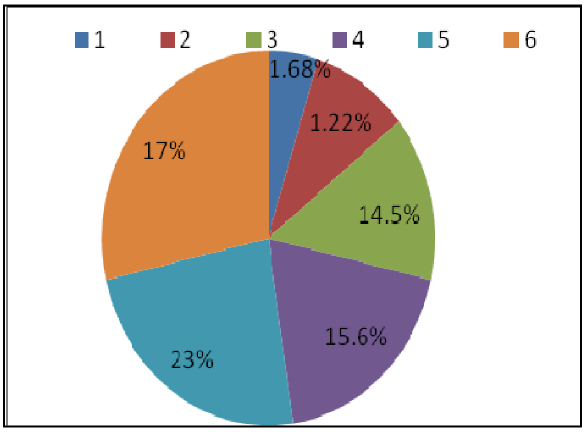

Fig. 7 Direct operation items cost drivers, 1- Nitride 2 - Phosphorus, 3 - CO2, 4 - Labour, 5- Power, 6- Fresh water

IV. CONCLUSIONS AND COMPARISON WITH OTHER WORKERS

The results indicated that the cost structure model was operated well and gave a good out come. The calculated cost of biomass was ranged between 0.137 ($/kg) for 100 ha and o.132 ($/kg) for 500 ha. This result was less than the cost calculated by other researches like[34], [29], [35], [36], [37], [38], [39]. The cost of algal-biofuel was in the range of $3.5 - $3.42 per gallon. According to this result, the parameter costs sensitive to large area. Also the total production cost is still high, so to gain profit the barrel price must be $150 or higher.. However the ($1) deferent between price of crude oil and biofuel gallon represent the contribution rate to prevent environment from green gas emission.

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